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Canadian Water Quality Guidelines: Permethrin

Scientific Supporting Document

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NOTE TO READERS

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This document provides the background information and rationale for the development of the Canadian Water Quality Guidelines for permethrin. For additional technical information regarding these guidelines, please contact:

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ABSTRACT

This scientific supporting document describes the development of Canadian Water Quality Guidelines for permethrin. It contains a review of technical background information on the chemical and physical properties of permethrin, a review of uses in Canada, the distribution and behaviour of permethrin in the environment, and the toxicological effects of permethrin on freshwater and marine aquatic life, terrestrial crops, mammals, and birds. This information is used to derive ambient water quality guidelines for permethrin. The guidelines in this document are based on the best available toxicity data at the time of writing, May 2005.

Permethrin is an active ingredient of insecticide products used for general domestic use, for control of ectoparasites (e.g., flies on cattle, fleas or ticks on pets), control of chewing insect pests on a variety of agricultural crops, control of forest pests, as a perimeter application to control adult mosquitoes, and for application to military clothing and mosquito netting. Permethrin is non-volatile, practically insoluble in water, and adsorbs strongly to soil and sediment particles. Transformation and degradation of permethrin occurs primarily by cleavage at the ester bond followed by oxidation. It dissipates rapidly from surface waters with a half-life of <4 days, primarily due to removal from the water column through adsorption to sediment, rather than degradation. Permethrin is more persistent in sediment, as well as in soil where it can have a half-life of 5 to 42 days. Due to permethrin's low persistence, low water solubility, and strong sorption, the potential for permethrin to move to groundwater is very low.

Most analytical methods for measuring permethrin use gas chromatography-mass spectrometry, but the methods can vary greatly in their detection limits (e.g., from 0.0005 to 0.02 µg/L). Only a limited number of studies have looked at permethrin concentrations in Canadian waters. In four monitoring studies (from BC, Ontario, Quebec and PEI), permethrin concentrations were below detection in most water samples. The highest concentration of permethrin reported from these studies was 2.7 ng/L. Permethrin was detected more frequently in sediment samples; the highest reported concentration in sediment was 11 µg/kg.

Permethrin is a neurotoxin that acts by prolonging the sodium ion permeability of neuron membranes, resulting in repetitive activity in sensory and motor systems. Symptoms of permethrin intoxication include restlessness, incoordination, hyperactivity, prostration and paralysis. Sensitivity of non-target organisms to permethrin can vary greatly among taxa. Permethrin has high toxicity to aquatic invertebrates and fish, low toxicity to algae and amphibians, and is practically non-toxic to mammals (including humans) and birds. Transformation products of permethrin are less toxic than the parent compound in most organisms, the exception being some algae.

Canadian water quality guidelines for the protection of agricultural water uses (i.e., irrigation and livestock watering) were not derived for permethrin due to insufficient data. From the data available, plants, mammals and birds appear to be relatively insensitive to permethrin, and adverse effects due to permethrin in irrigation or livestock water would not be expected to occur under recommended rates of use.

Sufficient toxicity data were available to derive interim freshwater and marine water quality guidelines for permethrin. The interim freshwater guideline was based on a 21-day LOEC of 0.042 µg a.i./L for immobility in nymphs of the stonefly *Pteronarcys dorsata* (Anderson 1982).

This concentration was multiplied by a safety factor of 0.1 to obtain an interim water quality guideline of 0.004 µg a.i./L.

The interim marine guideline was based on a 96-hour LC50 of 0.02 µg a.i./L for *Mysidopsis bahia* (Schimmel et al. 1983). Because this was an acute study, and because permethrin is non-persistent, the concentration was multiplied by an application factor of 0.05 (CCME 1991) to obtain an interim water quality guideline of 0.001 µg a.i./L.

These guidelines are intended to protect all forms of aquatic life and all aspects of aquatic life cycles during an indefinite period of exposure to the water column (CCME 1991).

RÉSUMÉ

Ce document scientifique est un compte rendu des Recommandations canadiennes pour la qualité des eaux relatives à la perméthrine. On y trouve un aperçu des renseignements techniques généraux sur les propriétés chimiques et physiques de la perméthrine, de ses utilisations au Canada ainsi que de sa distribution et de son comportement dans l'environnement, de même qu'une analyse de ses effets toxicologiques sur les organismes dulcicoles et marins, sur les cultures terrestres, sur les mammifères et sur les oiseaux. Cette information sert à formuler les recommandations pour la qualité de l'eau visant la perméthrine. Les recommandations présentées ici sont basées sur les meilleures données toxicologiques disponibles au moment de la rédaction du document, en mai 2005.

La perméthrine est un ingrédient actif de divers produits insecticides destinés à des usages domestiques généraux dont :

- La lutte contre les ectoparasites (p.ex. les insectes piqueurs du bétail, les puces et les tiques chez les animaux domestiques),
- La lutte contre les insectes ravageurs des cultures et des forêts,
- L'épandage autour des édifices pour lutter contre les moustiques adultes,
- L'application sur les vêtements militaires et les filets moustiquaires.

La perméthrine n'est pas volatile. Elle est pratiquement insoluble dans l'eau et se lie fortement aux particules du sol et aux sédiments. Elle est transformée et dégradée principalement par clivage de la liaison ester suivi d'une oxydation. Elle se dissipe rapidement des eaux de surface (demi-vie < 4 jours). Sa disparition de la colonne d'eau est principalement causée par l'adsorption dans les sédiments plutôt que par la dégradation. Elle est plus persistante dans les sédiments ainsi que dans le sol (demi-vie de 5 à 42 jours). Vu sa faible persistance, sa faible solubilité dans l'eau, et sa forte liaison, la perméthrine présente peu de risque de contaminer les eaux souterraines.

La plupart des méthodes d'analyse utilisées pour mesurer la perméthrine dans l'eau font appel à la chromatographie gazeuse couplée à la spectrométrie de masse, mais leurs limites de détection peuvent varier grandement (p. ex. de 0,0005 à 0,02 µg/L). Seul un petit nombre d'études se sont penchées sur les concentrations de perméthrine dans les eaux canadiennes. Dans quatre études de suivi (réalisées en Colombie-Britannique, en Ontario, au Québec et à l'Île-du-Prince-Édouard), les concentrations de perméthrine sont inférieures à la limite de détection dans la plupart des échantillons d'eau. La plus forte concentration signalée dans ces études s'élève à 2,7 ng/L. La perméthrine est plus souvent détectée dans les échantillons de sédiments, la plus forte concentration signalée dans ce cas s'élève à 11 µg/kg.

La perméthrine est une substance neurotoxique qui agit en prolongeant la perméabilité des membranes neuronales à l'égard de l'ion sodium, ce qui donne lieu à une activité répétitive dans les systèmes sensoriel et moteur. Les symptômes d'intoxication causés par cet insecticide comprennent l'agitation, l'incoordination, l'hyperactivité, la prostration et la paralysie. La sensibilité à la perméthrine des organismes non ciblés peut varier énormément selon les taxons. Cet insecticide est très toxique pour les invertébrés aquatiques et les poissons, peu toxique pour les algues et les amphibiens, et pratiquement non toxique pour les mammifères (y compris les humains) et les oiseaux. Les produits de transformation de la perméthrine sont moins toxiques pour la plupart des organismes que la perméthrine elle-même, sauf pour certaines algues.

À cause de l'insuffisance des données, aucune recommandation canadienne pour la qualité de l'eau portant sur le protection des utilisations agricoles de l'eau (soit l'irrigation et l'abreuvement du bétail) n'a été formulée pour la perméthrine. D'après les données disponibles, les plantes, les mammifères et les oiseaux semblent relativement insensibles à la substance, qui ne devrait donc pas avoir d'effets néfastes dans le cadre de l'irrigation ou de l'abreuvement du bétail lorsqu'elle est utilisée conformément aux instructions.

On dispose par contre de données suffisantes sur la toxicité pour formuler des recommandations provisoires sur la qualité de l'eau douce et de l'eau de mer visant la perméthrine. Ces recommandations provisoires sont basées sur une CMEO sur 21 jours de 0,042 µg i.a./L pour l'immobilisation des larves du plécoptère *Pteronarcys dorsata* (Anderson, 1982). Cette concentration a été multipliée par un facteur de sécurité de 0,1 pour obtenir une recommandation provisoire pour la qualité de l'eau de 0,004 µg i.a./L.

La recommandation provisoire pour l'eau de mer se base sur une CL50 sur 96 heures de 0,02 µg i.a./L pour le *Mysidopsis bahia* (Schimmel *et al.*, 1983). Comme il s'agit d'une étude aiguë et que la perméthrine n'est pas persistante, la concentration a été multipliée par un facteur de 0,05 (CCME, 1991) pour obtenir une recommandation provisoire pour la qualité de l'eau de 0,001 µg i.a./L.

Ces recommandations devraient protéger toutes les formes d'organismes aquatiques et tous les aspects du cycle de vie de ces organismes pour une période indéfinie d'exposition dans la colonne d'eau (CCME, 1991).

LIST OF ACRONYMS

AF	application factor
a.i.	active ingredient
ASTM	American Society for Testing and Materials
ATPase	adenosine triphosphatase
BCF	bioconcentration factor
CAS	Chemical Abstracts Service
CWQG	Canadian Water Quality Guidelines
DCVA	3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylic acid
DDT	dichloro diphenyl trichloroethane
DO	dissolved oxygen
EC50	median effects concentration
ELISA	enzyme-linked immunosorbent assay
EQS	Environmental Quality Standard
FAV	Final Acute Value
$IWQG_{FAL}$	interim water quality guideline for the protection of freshwater aquatic life
$IWQG_{MAL}$	interim water quality guideline for the protection of marine aquatic life
LC50	median lethal concentration
LD50	median lethal dose
LOEC/LOEL	lowest observable effects concentration / level
MPC	Maximum Permissible Concentration
NC	Negligible Concentration
NOEC	no observable effects concentration
PBAl	3-phenoxybenzyl alcohol
PBAc	3-phenoxybenzoic acid
PCPA	Pest Control Products Act
PMRA	Pest Management Regulatory Agency
SF	safety factor
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service

1.0 INTRODUCTION

This document describes the development of Canadian Water Quality Guidelines (CWQGs) for permethrin for the protection of aquatic life and for the protection of agricultural water uses. CWQGs are numerical limits based on the most current, scientifically-defensible toxicological data (i.e., toxicological data that fulfil the criteria for primary and secondary data as established in CCME 1991). They are nationally consistent values designed to protect, sustain and enhance the present and potential uses of a water body. CWQGs are developed under the auspices of the Canadian Council of Ministers of the Environment (CCME) and may be used by provincial, territorial, and federal jurisdictions to evaluate water quality. Often CWQGs form the scientific basis for site-specific guidelines or objectives used by managers in the various Canadian jurisdictions.

This document includes technical information on the chemical and physical properties of permethrin, production and uses, sources, and pathways for entry of permethrin into the Canadian environment. Available data on environmental fate and persistence are summarized. A comprehensive assessment of the toxicity of permethrin to aquatic life, as well as to crop plants and livestock, are presented to evaluate the environmental hazards posed by permethrin in water. Together, this information is used, in accordance with "A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life" (CCME 1991) and "Protocols for Deriving Water Quality Guidelines for the Protection of Agricultural Water Uses (Irrigation and Livestock Water)" (CCME 1993) to derive numerical water quality guidelines.

2.0 PHYSICAL AND CHEMICAL PROPERTIES

Numerous pest control products containing permethrin (CAS Registry Number 52645-53-1) as an active ingredient are registered in Canada under the Pest Control Products Act (PCPA). Permethrin is an odourless, colourless crystalline solid or a viscous liquid that is white to pale yellow. Permethrin has the molecular formula $C_{21}H_{20}Cl_2O_3$ and a molecular weight of 391.30 (Kidd and James 1991).

The IUPAC chemical name for permethrin is 3-phenoxybenzyl(1RS)-*cis*,*trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate. Permethrin is an ester of the dichloro analogue of chrysanthemic acid and 3-phenoxybenzyl alcohol (Figure 1). Technical products comprise a mixture of four stereoisomers due to the chirality of the cyclopropane ring. The *cis*-*trans* isomer ratio is 2:3 and the optical ratio of 1R:1S is 1:1, a racemic mixture (IPCS 1990). Therefore, permethrin contains the [1R, *trans*], [1R, *cis*], [1S *trans*] and [1S, *cis*] isomers in the approximate ratio of 3:2:3:2. The [1R, *cis*] isomer is the most insecticidally active among the isomers followed by the [1R, *trans*] isomer.

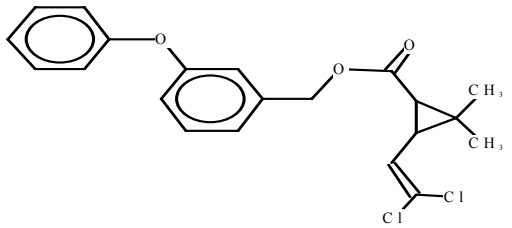

Figure 1 Chemical structure of permethrin (no stereochemistry identified)

The physical and chemical properties of permethrin are presented in Table 1. Permethrin has a melting point of 34-39°C, and a boiling point of 200-220°C (at 6.67 - 1.33 Pa); its density is 1.214 g/ml at 25°C (Meister 2004; Worthing and Walker 1987; FAO/WHO 1980; Wells *et al*. 1986; Hayes and Laws 1990). It has a Henry's Law Constant of 4.8 x 10^{-8} atm·m^3/mol at 20°C while its vapour pressure is 1.88 x 10^{-8} mmHg at 20°C (Montgomery 1993), indicating that it is non-volatile. Permethrin is practically insoluble in water, with a solubility of 0.006 mg/L at 20°C (Tomlin 2000), and is soluble or miscible in organic solvents such as acetone (450,000 mg/L), methanol (0.258 kg/kg @ 25°C), hexane (>1 kg/kg), and xylene (>1 kg/kg) (FAO/WHO 1980; Tomlin 2000); it is stable to heat, but unstable in alkaline media (Tomlin 2000; FAO/WHO 1980). Permethrin has a log K_{ow} reported to range from 2.88 to 6.5 (Schimmel *et al*. 1983; Montgomery 1993), and a log K_{oc} ranging from 1.32 to 2.79 (Montgomery 1993). Permethrin strongly adsorbs to soil and sediment, limiting its contamination of groundwater and potential for runoff into surface waters.

Table 1 Physical-Chemical Properties of Permethrin

Physical-Chemical Property	Permethrin	Reference(s)
Appearance	Yellow to brown crystal or viscous liquid	IPCS 1984
Chemical Name	IUPAC: 3-phenoxybenzyl (1RS)-*cis*,*trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate CAS: (3-phenoxyphenyl)methyl (1RS)-*cis*,*trans*-3-(2,2-dichloroethenyl)-2,2 dimethylcyclopropanecarboxylate	IPCS 1984
Chemical Formula	$C_{21}H_{20}Cl_2O_3$	Kidd and James 1991
CAS number	52645-53-1	IPCS 1984
Molecular Weight	391.30	Kidd and James 1991
Water Solubility	0.006 mg/L @ 20°C	Tomlin 2000
Melting Point	34-39 ºC	Hayes and Laws 1990
Vapour Pressure	1.88×10^{-8} mmHg @ 20°C 1.5 – 2.5 µPa @ 20°C	Montgomery 1993 Wells et al. 1986
Partition Coefficient (log K_{ow})	2.88-6.5	Schimmel *et al*. 1983; Montgomery 1993
Soil Adsorption Coefficient (log K_{oc})	1.32-5	Montgomery 1993; EXTOXNET 1996

2.1 Analytical Methods

In general, the procedure used to analyse residue and environmental samples for permethrin consists of (1) extraction, (2) partitioning, (3) chromatographic separation, and (4) quantitative and qualitative analysis of the insecticide by analytical instruments (IPCS 1990). Depending on the sample type, hexane, acetone, chloroform or acetonitrile is used to extract permethrin from the sample. After solvent extraction, permethrin is further cleaned-up by chromatography using silica gel or florisil. Lastly, gas chromatographic methods including electron capture detector, selected ion monitoring with mass spectroscopy or flame ionization detector are examples of methods used to determine permethrin concentrations in the samples. A summary of analytical methods for the analysis of permethrin in various media is presented in IPCS (1990).

For analysis of water samples, Environment Canada's National Laboratory for Environmental Testing has an analytical method for pyrethroids, including permethrin. Permethrin is extracted from water samples using solid-phase extraction C18 cartridges, which are eluted with methanol. The extract is then evaporated to 1 mL and injected into a gas chromatograph – mass spectrometer with detection using electron impact ionization. The detection limit for this method is 0.005 µg/L (Ed Sverko, National Laboratory for Environmental Testing, Environment Canada, Burlington, Ontario, personal communication).

The Ontario Ministry of Environment also has a standard method for analysis of various pesticides, including permethrin, in water, effluent and wastewater (OMOE 2002). The sample is extracted with hexane, concentrated, and then reconstituted in toluene. It is then analysed by gas chromatography – mass spectrometry. The method detection limit for permethrin is

approximately 0.02 µg/L (Paul Yang, Ontario Ministry of the Environment, Etobicoke, Ontario, personal communication).

Bonwick et al. (1995) developed a method for analysing permethrin concentrations in water using gas chromatography-mass spectrometry operated in the negative chemical ionization mode with selected-ion monitoring. The analytical method quantitation limit is 0.0005 µg/L. In addition to testing the analytical method with laboratory spiked samples, the method was also successfully used to detect permethrin in field samples from a contaminated stream without the need for any additional clean-up of the samples (Bonwick et al. 1995).

Specific examples of the analytical approach used to evaluate concentrations of permethrin in other environmental media include Bonwick *et al*. (1995), Bonwick *et al*. (1996), and Yasin *et al*. (1995). For analysis of permethrin in sediment, Bonwick et al. (1995) describe a method using gas chromatography-mass spectrometry that has an analytical method quantitation limit of 0.005 µg/kg dry weight. Bonwick *et al*. (1996) developed an ELISA (enzyme-linked immunosorbent assay) method for analysis of permethrin in fish tissue, with a detection limit of 10 µg/kg dry weight. Yasin *et al*. (1995) report a practical quantitation limit in the range of 1 to 5 µg/kg dry weight, for the detection of permethrin in fish, sediment, or moss. IPCS (1990) describes a variety of approaches for residue analysis in different types of food, with detection limits that range from 5 to 200 µg/kg (note: it is not indicated whether these are in wet or dry weight).

3.0 PRODUCTION AND USES

Permethrin was first synthesized in 1973 at the Rothamstead Experimental Station in Harpenden, England. It is currently produced by companies including (but not limited to): Agro-Chemie, BASF, Bayer, FMC, Meghmani, Mitchell Cotts, Sanachem, Sumitomo, Syngenta, Tagros, and United Phosphorus (Tomlin 2000; Meister 2004). Permethrin is not produced in Canada; therefore, all permethrin in use here has been imported. No data could be found on how much permethrin is imported into Canada. Sales and use data collected by individual jurisdictions can be used to give an indication of the amount of permethrin sold annually in Canada. Available permethrin sales and use data include 1998 data from Alberta (Richard Casey, Alberta Environment, Edmonton, Alberta, personal communication), 2003 data from Ontario (McGee et al. 2004), and 2002 data from Prince Edward Island (Don Reeves, Pesticide Regulatory Program, PEI Environment and Energy, Charlottetown, PEI, personal communication). The combined total annual sales for these three provinces is estimated at 1077.6 kg active ingredient. This total is at best an estimate based upon a patchwork of data from these Canadian jurisdictions. However, it is assumed that the sales and use of permethrin, year-to-year, is relatively stable, thus combining data from different years can provide a useful estimate. In 2003, approximately 647 kg active ingredient (a.i.) of permethrin was used on agricultural crops in Ontario, of which 249 kg a.i. was used on vegetables (McGee et al. 2004). In Nova Scotia the sales data in 2003, although incomplete, indicates that approximately 150 litres of pesticide formulation with permethrin as the a.i. was sold; it does not appear to be widely used (Don Burns, Nova Scotia Department of Environment and Labour, Halifax, Nova Scotia, personal communication).

In Canada, the Pest Management Regulatory Agency regulates the use of active ingredients under the *Pest Control Products Act*. Permethrin is registered for use in Canada in over 230 products, including technical grade active ingredient and formulated pesticides (PMRA 2004). Approximately 72% of the products are registered for domestic use, 17% are registered for

commercial use, and 1% is registered for restricted use, while 8% and 2% are registered as manufacturing concentrate and technical actives, respectively (PMRA 2004). Trade and other names used for permethrin-based pesticides include, but are not limited to, Ambush, Atroban, Dragnet, Ectiban, Evercide, Permanone, Pounce, Pramex, and Raid Fumigator. The various permethrin-based pesticides registered in Canada are used for a wide variety of purposes including: insect control on agricultural crops, orchards, nurseries and in greenhouses; flea and tick control on household pets; biting insect control in livestock (e.g., treated ear tags); general insecticide products for domestic use; as a perimeter application for control of adult mosquitoes around buildings; application to fabrics for military use; and others (PMRA 2004). Permethrin is also registered for restricted use on commercial woodlots (PMRA 2004), but was used for forest pest control much more extensively in the past (Sundaram 1991; Mian and Mulla 1992).

In agriculture, permethrin is primarily used to control larvae (as well as adults and eggs) of chewing insect pests such as *Lepidoptera* (butterflies and moths) and *Coleoptera* (beetles). For crop application, it is available in dusts, emulsifiable concentrates and wettable powder formulations. Permethrin is used in Canada to control pests on nut, fruit, vegetable, tobacco, oil seed, rape, wheat, barley, ornamental, mushroom, potato and cereal crops. Typical application rates for permethrin are 17-70 g/ha on nursery trees and shrubs, 35-150 g/ha on vegetables, 70-100 g/ha on tobacco and cereals, and 100-200 g/ha on fruit (PMRA 2004).

4.0 SOURCES TO THE ENVIRONMENT

In Canada, permethrin is used in a number of insecticidal products designed to control a wide range of pests. It is used in agricultural practices, forestry, and domestically. Given its variety of practical applications, the sources of permethrin to the environment are multifold. Direct application of permethrin to control terrestrial pests can result in residues on soil and vegetation, and exposure of non-target terrestrial biota. Direct application of permethrin to water bodies is not permitted in Canada, and labels on permethrin products specify that they should not be applied by ground equipment within 15 metres or by any aerial application within 100 metres of any body of water, especially productive fisheries or waterfowl habitats (PMRA 2004). Nonetheless, use of permethrin could potentially result in unintended transport to aquatic habitats and indirect contamination through spray drift, atmospheric deposition, leaching, soil erosion, and runoff. Several studies have looked at the potential for transport of permethrin to surface waters through drift from ground or aerial spraying (e.g., Helson et al. 1986; Payne et al. 1988; Frank et al. 1991).

5.0 ENVIRONMENTAL FATE AND BEHAVIOUR

5.1 Transformation Products

The transformation products of permethrin in the environment are generally considered less toxic than the parent compound; however, at least one study has shown that permethrin transformation products are more toxic to algae than the parent compound (Stratton 1981). Typical transformation products from ester hydrolysis include PBAl [3-phenoxybenzyl alcohol], DCVA [3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylic acid], 3-(2,2-dichlorovinyl)-2-methylcyclopropane-1,2-dicarboxylic acid and 3-(4-hydroxyphenoxy)-benzyl-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate, amongst others (Jordan and Kaufman,1986; Kaneko *et al*., 1978; Leahey and Carpenter, 1980; Rawn et al. 1982). Microbial metabolism of PBAl also typically produces PBAc [3-phenoxybenzoic acid] (Kaufman et al.

1981). Many of these transformation products are further oxidized and degraded and, depending on environmental conditions, can undergo complete mineralization (Jordan *et al*. 1982; Penick Corporation, 1979). Examples of some transformation products are illustrated in Figure 2.

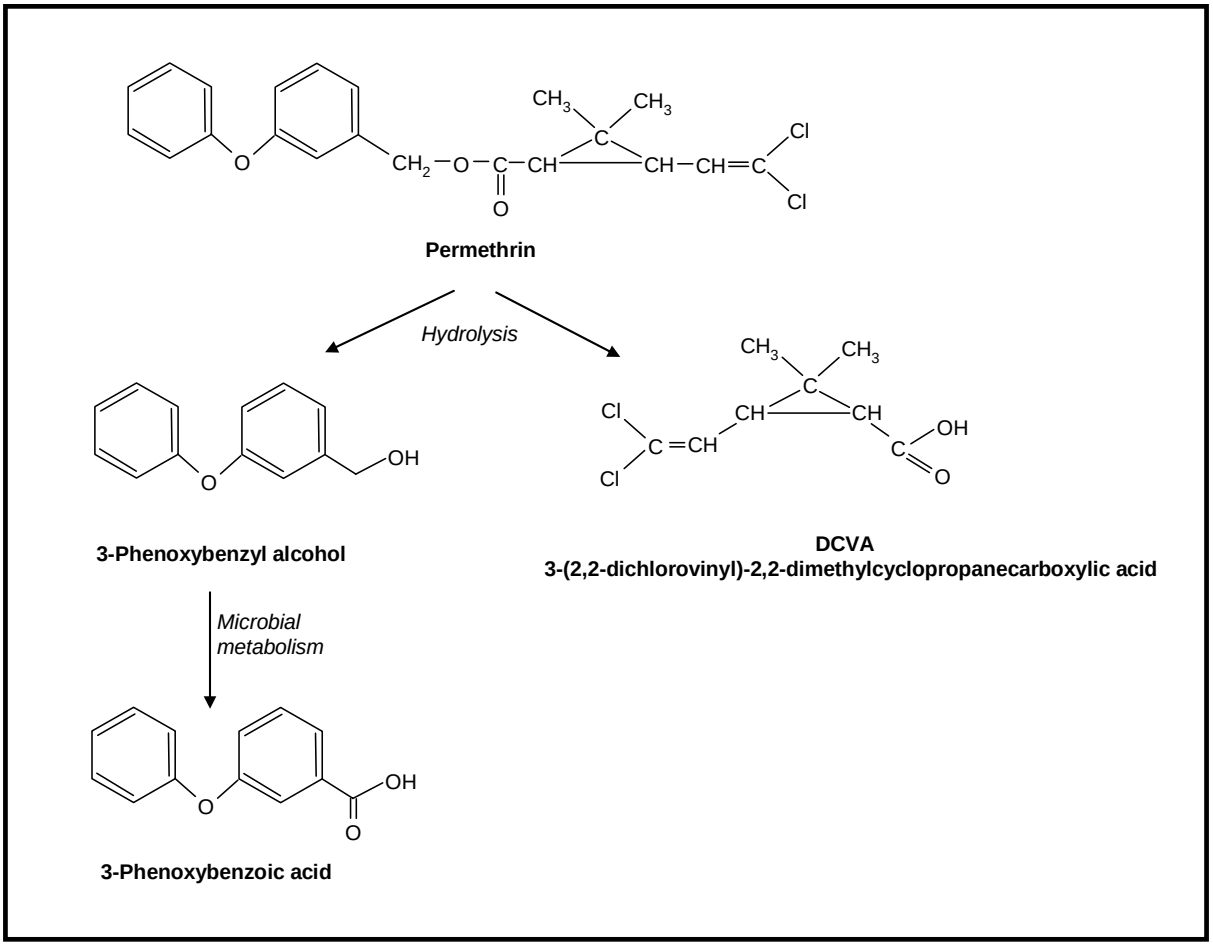

Figure 2. Structures of typical permethrin transformation products.

5.2 Fate in Water and Sediment

The main types of fate processes affecting permethrin in water are adsorption, hydrolysis, photolysis, and biodegradation. When permethrin enters a water body, rapid loss due to adsorption occurs over the first 1 to 3 days (Allan et al. 2001; Agnihotri et al. 1989). Permethrin remaining in the water column transforms and degrades primarily through the hydrolysis of the ester bond and oxidation (Lutnicka *et al*., 1999). Photolysis can also play a role in permethrin transformation. Rawn et al. (1982) found that immediately following exposure to sunlight, isomerization of the *trans*-isomer to the *cis*-isomer and vice-versa occurred, with rapid transformation during the first 24 hours. Photolysis half-lives of 19.6 and 27.1 hours for the *trans*- and *cis*-isomers, respectively were reported (Rawn et al. 1982). By comparing results in light-exposed flasks with darkened flasks, they estimated that photolysis accounted for 27-34% of the permethrin loss observed (Rawn et al. 1982). Schimmel *et al*. (1983) found that permethrin in seawater had a half-life of 14 days when exposed to sunlight, and >14 days in the absence of light. The presence of sediment particles can reduce photoisomerization rates, due to adsorption. Allan et al. (2005) found that in deionized water permethrin had a

photoisomerization rate of 9.02 x 10^{-8} s^{-1} (half-life of 89 days), whereas in river water containing suspended solids, or when a sediment bed was present, the photoisomerization rates were 8.20 x 10^{-8} s^{-1} (half-life of 98 days) and 7.83 x 10^{-8} s^{-1} (half-life of 102 days), respectively. In fresh water, Lutnicka et al. (1999) measured half-lives for permethrin of 1.1 to 3.6 days. Muir et al. (1983) found that permethrin in water degraded exponentially over time, with 47 to 64% being converted to transformation products after 24 hours. According to the classification scheme used by the Pest Management Regulatory Agency (PMRA) (McEwen and Stephenson 1979), permethrin would be considered non-persistent in water. The transformation products PBAl and PBAc are even less persistent than permethrin, but DCVA is slightly more persistent (Rawn et al. 1982).

Permethrin has been found to bind to suspended solids, dissolved organic matter and sediments (Liu *et al*., 2004; Lee *et al*., 2004). As much as 97% of permethrin applied to the water surface may partition to the sediment (Allan et al. 2001). Liu et al. (2004) conducted two studies to look at the phase distribution of synthetic pyrethroids (including permethrin). In one study, they analysed runoff effluents collected from a nursery site, and found that 10 to 27% of the synthetic pyrethroids were in the freely dissolved phase, with the remainder adsorbed to suspended solids and dissolved organic matter. In the second study, they analysed stream waters that had been spiked with *cis*-bifenthrin and both *cis*- and *trans*-permethrin. In the stream water, only 0.4 to 1.0% of the synthetic pyrethroids were in the freely dissolved phase (Liu et al. 2004). In a laboratory adsorption-desorption study, more than 95% of permethrin in aqueous solution was rapidly adsorbed to sediment, and desorption was minimal even after several water rinses (Sharom and Solomon 1981). Permethrin is more persistent in sediments than in water (Hartley and Kidd 1983; Wagenet *et al*. 1985). Muir et al. (1983) found that >94% of permethrin in sediments remained undegraded after 48 hours. Agnihotri et al. (1989) examined the fate and persistence of permethrin applied at rates of 100 and 200 g a.i./ha to tubs containing water and sediment. Permethrin was first detected in the sediment on day 3, presumably after sorption to suspended particles which later settled. The permethrin persisted in the sediment until about day 30 (Agnihotri et al. 1989). Adsorption to coarse solid phases may render permethrin less bioavailable to microorganisms capable of metabolizing it, thereby increasing its persistence; however, sorption to fine particles, algal cells and bacterial biofilms in sediment may actually enhance the bioavailability of permethrin to benthic invertebrates (Allan et al. 2005). Lee et al. (2004) isolated several species of gamma Proteobacteria from sediments that were capable of degrading permethrin. They noted that *trans*-permethrin was transformed more rapidly than *cis*-permethrin (Lee et al. 2004).

In field tests, a forest block was sprayed with permethrin at 17.5 g/ha in Ontario and Quebec, Canada (Kingsbury and Kreutzweiser 1980; Kreutzweiser, 1982). Measured residues of permethrin in water persisted for less than 96 hours in ponds and less than 48 hours in streams. In one case, residue concentrations in water fell to below the detection limit in a stream after 6 to 24 hours. Permethrin residues were found in water 2.1 km downstream from the treatment block 6 hours after application, but did not persist beyond 96 hours. It is possible that, after 96 hours, the permethrin had moved further downstream, or had partitioned into sediment. In the Ontario portion of the field test, accumulation of permethrin in pond sediment was minimal and no residue was found in stream sediments. Residue concentrations in foliage, soil and litter remained detectable to the end of the 58-day sampling period. In the Quebec site, low concentrations of permethrin in sediment were found in ponds and streams residing in the treatment block and minimal concentrations in the sediment of streams were found 4.5 km downstream. After a second application at the Quebec site, mean residues concentrations of

permethrin in forest litter increased substantially but fell to non-detectable levels within 59 hours.

Sundaram and Curry (1991) dripped an emulsifiable concentrate of permethrin into a small headwater stream in Ontario such that the nominal concentration of permethrin at the application site was 16 µg/L. Permethrin concentrations in the water had dropped below the detection limit of 0.005 µg/L after 4.5 hours. Drifting invertebrates were found to have accumulated permethrin, with higher concentrations measured in the smaller size classes. Loss of permethrin to concentrations below the detection limit of 0.75 mg/kg tissue took approximately 12 hours in the large invertebrates, and 48 hours in the small invertebrates. Periphyton were also found to sorb and accumulate permethrin. Residues in the periphyton were more persistent than in the invertebrates, such that levels below the detection limit of 0.75 mg/kg were not reached until after 7 to 13 days (Sundaram and Curry 1991).

Dietrich et al. (1996) studied two rivers in Germany that were accidentally contaminated with a large quantity of permethrin, resulting in extensive fish kills and loss of other aquatic fauna. Four months after the contamination, high concentrations of permethrin were still detected in sediment, algae and snails. The persistence of permethrin in sediments and the food chain for this extended period of time was unexpected, and the authors noted that even after four months the permethrin concentrations present posed a health hazard to fish.

Because permethrin has a low density and is practically insoluble in water, it may form a surface film when brought into contact with stagnant or slow moving water. This condition significantly reduces the likelihood of permethrin reaching bottom sediment (Kingsbury and Kreutzweiser 1980). However, it would result in greater exposures for surface-dwelling organisms such as insects.

5.3 Fate in Soil

Permethrin is not expected to leach from soil (Carroll *et al*. 1981) or to contaminate groundwater (Wagenet *et al*. 1985) because it binds strongly to soil particles and is practically insoluble in water (Carroll *et al*. 1981; U.S. DASCS 1990). Using column leaching studies, Kaufman *et al*. (1981) examined the mobility of permethrin and its transformation products in soil. They concluded that permethrin is immobile and cannot be readily leached. The transformation products DCVA [3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylic acid] and PBAc (3-phenoxybenzoic acid) were somewhat mobile in soil, while PBAl (3-phenoxybenzyl alcohol) had low mobility (Kaufman et al. 1981). The potential for pesticides to move into groundwater can also be evaluated by calculating a Groundwater Ubiquity Score (GUS), which is based on persistence and sorption. The GUS for permethrin is -1.5, indicating that it has an extremely low potential to move to groundwater (Vogue et al. 1994). According to the classification scheme used by PMRA (Goring et al. 1975), permethrin is slightly to non-persistent in soil with half-lives reported between 5-42 days (Kaufman *et al*. 1977; Kaneko *et al*. 1978; Williams and Brown 1979; Carroll *et al*. 1981; Jordan *et al*. 1982; Kidd and James 1991; Wauchope *et al*. 1992). Permethrin is readily broken down in most soils except organic types. The rates of transformation and degradation vary depending on the isomer (*cis*- or *trans*-), environmental conditions (*e.g*., temperature, pH, moisture content, oxidation potential), and microbial community present (Carroll *et al*. 1981).

Under laboratory conditions, permethrin was shown to degrade in soil with a half-life of 28 days or less. The *trans* isomer degraded more rapidly than the *cis* isomer with ester cleavage being the major initial transformation product (Kaufman *et al*. 1977). Microbial transformation was the major degradation pathway. Hydrolysis of the ester function was the primary degradation route followed by oxidation that eventually yielded carbon dioxide as the major final product. The rate of transformation and degradation is greatly influenced by the pH and redox potential. Under well-oxidized conditions, permethrin was practically fully degraded after 25 days at various pH while under reduced conditions only 40% of permethrin was degraded (Gambrell *et al*. 1981). Jordan *et al*. (1982) observed that the most rapid rate of degradation to mineralization occurred at 25°C compared to 10°C and 40°C. Increased moisture content in soils was also observed to increase degradation of permethrin (Lord *et al*. 1982).

Permethrin can also undergo photodegradation on a soil surface. When permethrin isomers were exposed on silt loam soil for 48 hours, 55% of permethrin was lost under sunlight compared to 35% lost in the dark. Again, the major degradation pathway was ester cleavage (Holmstead *et al*. 1978).

5.4 Fate in Vegetation

The fate of permethrin in vegetation has been investigated using bean plants and cotton plants. A depuration half-life of 7 and 9 days was reported for the *trans*- and *cis*-permethrin isomers deposited on these plants, respectively. Ester cleavage was the major transformation pathway. Several hydroxylated compounds and *cis*-*trans* interconversion compounds were identified as transformation products (Ohkawa *et al*. 1977). Transformation products of a similar nature are reported by Gaughan and Casida (1978). They found that about 30% of radiolabelled permethrin was lost from cotton plants within one week after application.

The uptake of permethrin and its transformation products by plants from soil was studied by Swaine *et al*. (1978). Under field conditions, no residues of permethrin and its metabolite residues (dichlorovinyl acid and 3-phenoxybenzyl alcohol) were detected in different crop types sown 60 days after soil treatment. George (1985) reported that permethrin and its metabolite residues had declined 85% within seven days after application on seven agricultural crops.

5.5 Bioconcentration and Bioaccumulation

A number of studies have examined whether permethrin tends to bioconcentrate, or would be likely to bioaccumulate, by experimentally determining bioconcentration factors (BCFs) for permethrin in various aquatic organisms. A BCF is a measure of the tendency of a substance to migrate from water to the body tissues of aquatic organisms where it can accumulate and become concentrated (Rand et al. 1995). BCFs that have been measured in controlled laboratory or mesocosm studies for permethrin range from 44 to 2800 (Table 2). Therefore, according to the criteria of the Toxic Substances Management Policy, permethrin would not be classified as a bioaccumulative substance (Environment Canada 1995). Bonwick et al. (1996) estimated a considerably higher BCF for *Salmo trutta* (brown trout) of 60,176; however, this was based on analyses of field-collected fish for which the exposure duration was unknown.

Table 2. Bioconcentration Factors for Various Aquatic Organisms

Species	Mean BCF	Exposure duration (days)	Reference
Freshwater Algae / Plants			
Anabaena sp. (blue-green algae)	126 (57 – 813)	5	Kumar et al. 1988
Aulosira fertilissima (blue-green algae)	594 (46 – 2373)	5	Kumar et al. 1988
Lemna minor (duckweed)	202 (*trans*-isomer) 151 (*cis*-isomer)	5	Lockhart et al. 1984
Freshwater Invertebrates			
Chironomus tentans (midge)	44 (*trans*-isomer) 61 (*cis*-isomer)	1	Muir et al. 1985
Helisoma trivolvis (snail)	800 (± 150 SD)	28	Spehar et al. 1983
Pteronarcys dorsata (stonefly)	183	28	Anderson 1982
Freshwater Fish			
Oncorhynchus mykiss (rainbow trout)	84 (*trans*-isomer) 113 (*cis*-isomer)	1	Lockhart et al. 1984
Oncorhynchus mykiss (rainbow trout)	477[a] (*cis*-isomer) 1849[b]	4	Muir et al. 1994
Pimephales promelas (fathead minnow)	2800 (± 700 SD)	32	Spehar et al. 1983
Marine			
Crassostrea virginica (Eastern oyster)	1900	31	Schimmel et al. 1983
Cyprinodon variegatus (sheepshead minnow)	480	28	Hansen et al. 1983
Salmo salar (Atlantic salmon)	73	4	McLeese et al. 1980

[a] BCF based on concentration of parent permethrin
[b] BCF based on concentration of total 14C-labelled compounds (includes permethrin and degradation products)

6.0 CONCENTRATIONS IN CANADIAN WATERS

There are very limited data available on concentrations of permethrin in Canadian waters as only a few stations regularly monitor for it. Most of the data available are from specific monitoring studies that looked at the occurrence of various pesticides.

In Ontario, surface water samples were collected between May and August of 2003 from Indian Creek (an urban creek in Burlington) and Vineland Creek (an agricultural creek in the Niagara fruit growing area). Analyses of the samples showed no detection of permethrin (at a detection limit of 0.005 µg/L) or any other pyrethroid insecticides (John Struger, Environment Canada – Ontario Region, personal communication). A study in which surficial sediments from 60

tributaries to Lake Ontario and Lake Erie were analyzed found that *cis*-permethrin was detected in 3% of the sediments, and *trans*-permethrin in 2% (Environment Canada 2004).

In Quebec, water samples were collected and analyzed for permethrin in 1996 from three streams located near apple orchards (Abbott's Corner and Boffin at Frelighsburg, and Déversant du Lac at Rougemont). Permethrin was detected in only trace amounts in the stream at Rougemont (Giroux 1998).

In PEI, water and sediment samples were collected and analyzed for permethrin from three watersheds (Souris, Wilmot and Mill) in 2003. Permethrin was detected in 4 out of 30 samples of stream sediments, with the highest concentration measured at 10.85 µg/kg (ppb). Permethrin was not detected in run-off or stream water samples collected at the same time (detection limit of 5 µg/L) (Environment Canada 2004; Jamie Mutch, PEI Dept. of Environment, Energy and Forestry, personal communication).

In British Columbia, 6 sites in the Lower Fraser Valley and Duck Lake were monitored for permethrin. Concentrations were below the detection limit in all but two sites, Cohilickhan Slough (2.70 ng/L) and Hope Slough (0.61 ng/L) (Environment Canada 2004).

The results of these limited monitoring studies in Canadian waters are comparable to monitoring results from surface waters in the United States. In the U.S. Geological Survey's National Water Quality Assessment (NAWQA) Data Warehouse, the vast majority of sites sampled for permethrin reported non-detects (typically with a detection limit of 0.005 µg/L). At the few locations where permethrin was detected, concentrations did not exceed 0.014 µg/L (USGS 2003).

Given the low water solubility and high sorption of permethrin to soil particles, leaching of permethrin is limited, and thus the risk of groundwater contamination by permethrin is very low. Nonetheless, there have been detections of permethrin in groundwater, though typically at a very low frequency. For example, in a survey of 102 farm wells in Nova Scotia, permethrin was detected in one well at a concentration of 0.05 µg/L (the detection limit was 0.02 µg/L) (Moerman and Briggins 1994; Briggins and Moerman 1995). In a study of U.S. groundwater, permethrin was detected in 2 out of a total of 3023 samples, with a maximum concentration of 0.007 µg/L (USGS 1998).

6.1 Guidelines from Other Jurisdictions

Water quality guidelines for permethrin have been derived in Canadian provincial and international jurisdictions. Table 3 presents water quality guidelines for Québec, The Netherlands, and the United Kingdom.

Quebec water quality criteria were derived following the protocol used by the Ministère de l'Environnement du Québec (MENVIQ 1990), which is largely based on U.S EPA methods (Stephan et al. 1985). The Final Acute Value (FAV) is an estimate of the concentration corresponding to a cumulative probability of 0.05 in the acute toxicity values for the genera. For permethrin, this was determined by calculating the geometric mean of the acute values for each genus. The genus means were then ranked, and a cumulative probability was calculated for each genus. Through a series of calculations, the FAV was determined from the four genera with cumulative probabilities closest to 0.05. The resulting FAV of 0.0884 µg/L was then divided by

2 to obtain the Acute Aquatic Life Criteria value of 0.044 µg/L (Guay et al. 2000). Due to the lack of a sufficient number of available chronic studies, the Chronic Aquatic Life Criteria value of 0.013 µg/L for permethrin was derived by dividing the Final Acute Value by an acute-to-chronic ratio of 6.7 (Guay et al. 2000).

In the UK, the Environmental Quality Standard (EQS) for permethrin in both fresh and marine waters is 0.01 µg/L (Zabel et al. 1988). This EQS was derived by considering both available laboratory toxicity tests and field data. In the literature reviewed, the most sensitive endpoints included a 28-d study in which 55% mortality was reported in *Brachycentrus americanus* at a concentration of 0.03 µg/L, and, no effect levels of 0.03 µg/L reported for both *Gammarus* and *Pteronarcys dorsata*. Application of safety factors of 10 for chronic data and 100 for acute data result in a standard within the range of 0.003 to 0.03 µg/L. By looking at field data on concentrations of permethrin measured in surface waters, and corresponding observations on biotic effects, it was concluded that levels of permethrin below 0.01 µg/L would not likely result in adverse effects on aquatic life (Zabel et al. 1988). This EQS has been written into regulations under the UK's Dangerous Substances Directive (Cole et al. 1999).

When appropriate data are available, The Netherlands preferentially uses statistical extrapolation methods to derive water quality guidelines (Crommentuijn *et al*. 1997). When insufficient data are available to use statistical extrapolation methods, as in the case of permethrin, guidelines are based on the lowest NOEC or $L(E)C_{50}$ divided by a safety factor. The maximum permissible concentration of 0.0003 µg/L for permethrin in fresh water was based on a NOEC of 0.003 µg/L for *Brachycentrus americanus* (Anderson 1982) divided by a safety factor of 10. For permethrin in marine waters, the maximum permissible concentration of 0.0002 µg/L was based on a LC_{50} of 0.02 µg/L for *Mysidopsis bahia* (Schimmel et al. 1983) divided by a safety factor of 100 (Crommentuijn et al. 1997).

Table 3 Water Quality Guidelines for Permethrin from Provincial and International Jurisdictions

Jurisdiction	Application	Guideline (µg/L)	Reference
The Netherlands	MPC[1]: Fresh water	0.0003	Crommentuijn et al. 1997
The Netherlands	MPC[1]: Marine water	0.0002	Crommentuijn et al. 1997
The Netherlands	NC[2]: Water	0.000002	Crommentuijn et al. 1997
United Kingdom	EQS[3]: Fresh water	0.01	Zabel et al. 1988
United Kingdom	EQS[3]: Marine water	0.01	Zabel et al. 1988
Quebec	Protection of aquatic life: Chronic (interim)	0.013	Guay et al. 2000
Quebec	Protection of aquatic life: Acute (interim)	0.044	Guay et al. 2000

Notes:
[1]Maximum Permissible Concentrations (MPC): The standard at which all aquatic species should be protected from adverse effects.
[2]Negligible Concentration (NC): Derived by dividing the MPC by 100, this is the value expected to cause negligible effects, accounting for possible toxicity from multiple substances.
[3]Environmental Quality Standard (EQS) – Annual Average: The highest concentration that an aquatic ecosystem can be exposed to without experiencing any adverse effects.

7.0 ENVIRONMENTAL TOXICITY

7.1 Mode of Action

Like other synthetic pyrethroids, permethrin is a neurotoxin that acts on the axons in the peripheral and central nervous systems (IPCS 1990). It prolongs sodium ion permeability of neuron membranes, which results in repetitive activity in the sensory and motor systems (IPCS 1984). There is also evidence that permethrin interferes with ATPase enzymes that maintain ionic concentration gradients across cell membranes (Solomon *et al*. 2001). In studies with cultured neurons from the great pond snail (*Lymnaea stagnalis*) and embryonic chicks, permethrin was observed to affect the outgrowth of neurites in a dose-dependant manner (Ferguson and Audesirk 1990). Permethrin caused both the regression of existing neurites as well as inhibiting the initiation of new neurite outgrowth. The authors speculated that these effects may have been caused by interference of permethrin with intracellular calcium regulation (Ferguson and Audesirk 1990). In studies with frog skin, Cassano et al. (2003) found that permethrin increased transepithelial sodium ion absorption, but speculated that this increased ion transport may have been caused by increases in intracellular calcium ion concentrations. Signs of poisoning caused by this insecticide include restlessness, incoordination, hyperactivity, prostration, and paralysis (Gammon *et al*. 1981).

Permethrin is very highly toxic to insects. It is both a stomach and contact insecticide, meaning that insects are poisoned by ingestion of treated crops as well as by direct contact of their body with dust particles or spray droplets of the insecticide. Permethrin is known to have a slight repellent effect and to effectively kill adult, eggs and larvae of target and non-target species. Permethrin insecticidal activity is as much as 100 times that of DDT (Belanger and Hamilton 1979). It is also known to be very highly toxic to aquatic life including fish and non-target invertebrates (Jarboe and Romaire 1991; Mokry and Hoagland 1990; Holdaway and Dixon 1988).

Permethrin is practially non-toxic to mammals and birds. It is readily absorbed through the intestinal tract, and only minimally absorbed through intact skin (IPCS 1984). Mammals and birds have the ability to metabolize permethrin rapidly, thereby making them less sensitive to concentrations of permethrin in the environment (Hunt and Gilbert 1977; IPCS 1990).

7.2 Aquatic Toxicity

The following sections examine the toxicity of permethrin to freshwater and marine biota. All permethrin concentrations reported are for the active ingredient (i.e., µg a.i./L) rather than for formulated products, unless otherwise noted.

7.2.1 Freshwater

7.2.1.1 Fish

Permethrin is known to be very highly toxic to fish (Glickman *et al*. 1982; Bradbury and Coats 1989; Lutnicka *et al*. 1999) though there are conflicting data on the toxicity difference between the *cis*- and *trans*-isomers of permethrin in fish (Haya 1989). Miyamoto (1976) reported that the *trans*- and *cis*- isomers have similar toxicity whereas other studies have observed greater toxicity for the *cis*-isomer. Most permethrin-based pest control products are mixtures of isomers. Permethrin toxicity appears to be enhanced by emulsifiable concentrate preparations (***i.e.***, formulations) and stereochemical structure (Miyamoto 1976).

Common toxicity symptoms include flailing gills, full and rapid contortions, and loss of equilibrium (Glickman *et al*. 1982). The mechanism of lethal action in fish involves numerous physiological systems including the nervous system, respiratory surfaces, and renal ion regulation (Haya 1989). The very high toxicity of permethrin to fish may have to do with the low capacity of some fish species to hydrolyse permethrin (Glickman and Lech 1981); fish seem to be deficient in the enzyme system that hydrolyzes pyrethroids (Demoute, 1989). Rates of elimination and metabolism in trout are lower than those reported in mammals (Bradbury and Coats 1989). Depuration half-lives for elimination and metabolic transformation of pyrethroids in trout are in excess of 48 hours whereas in mammals and birds elimination is in the range of 6 to 12 hours (Bradbury and Coats 1989). The half-life for parent compound depuration of *cis*-permethrin in rainbow trout was 37 hours (Muir et al. 1994). Lockhart et al. (1984) measured depuration half-lives in rainbow trout of 85 and 45 hours for *trans*- and *cis*-permethrin, respectively. Mean depuration half-lives in chironomids were 28 and 21 hours for the *trans*- and *cis*-isomers of permethrin, respectively (Muir et al. 1985). In duckweed, depuration half-lives of 400 and 460 hour were measured for *trans*- and *cis*-permethrin, respectively (Lockhart et al. 1984).

Kumaraguru and Beamish (1983) found that rainbow trout exposed to permethrin at concentrations of 0.6 and 1.25 µg a.i./L experienced increased basal metabolic rates and consequent effects on swimming speeds upon initial exposure. The fish were able to acclimate to the permethrin though, with basal metabolic rates returning to control levels after 13 days in the 0.6 µg a.i./L exposure, and after 32 days at 1.25 µg a.i./L.

Several toxicity studies are presented below to illustrate the impact of permethrin on freshwater fish species. A listing of toxicity studies can be found in Appendix A.

Acute Effects

Acute 96-h LC50 values for freshwater fish ranged from 0.62 µg a.i./L for juvenile rainbow trout (*Oncorhynchus mykiss*) (Kumaraguru and Beamish 1981) to 540 µg a.i./L for juvenile flagfish (*Jordanella floridae*) (Holdway and Dixon 1988) (Appendix A).

The two most sensitive acute effects were 96-h LC50 values of 0.62 µg a.i./L and 0.69 µg a.i./L reported by Kumaraguru and Beamish (1981) for juvenile rainbow trout exposed to permethrin at temperatures of 5 and 10°C, respectively. Several other studies also reported median lethal concentrations in a similar range. For example, 96-h LC50 values of 1.0, 1.6, 1.7, 2.06, 2.86, 3.17, 4.56, and 4.62 µg a.i./L have been reported for white sucker (*Catostomus commersonii*), Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*), Apache trout (*Oncorhynchus gilae apache*), channel catfish (*Ictalurus punctatus*), brook trout (*Salvelinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*), bluegill sunfish (*Lepomis macrochirus*), and western mosquitofish (*Gambusia affinis*), respectively (Holdway and Dixon 1988; Sappington et al. 2001; Thurston et al. 1985; Kumaraguru and Beamish 1981; Paul et al. 2005).

Several studies have looked at factors that may affect the acute toxicity of permethrin, including: age of test organisms, availability of food during testing, and presence of formulants.

Of the fish toxicity studies reviewed, adults generally appear to be less sensitive than earlier life stages (e.g., juvenile, fingerling and fry), with adult LC50s ranging from 38 to 314 µg a.i./L whereas LC50s for earlier life stages are typically < 25 µg a.i./L (Appendix A). This observation is based on only three acute studies that used adult fish as the test species; most of the fish studies available used pre-adult life stages for testing. There are a few exceptions, including studies on juvenile goldfish, juvenile flagfish, and fingerling rainbow trout, where LC50s were > 25 µg a.i./L, and in the case of the flagfish, as high as 540 µg a.i./L.

In studies with juvenile flagfish (*Jordanella floridae*) and larval white sucker (*Catostomus commersoni*), Holdway and Dixon (1988) looked at the effects of age and feeding on the toxicity of permethrin. The fish were subjected to a two-hour pulse exposure, and were then transferred to clean water for observation over the subsequent 96 hours. The flagfish were less sensitive than white sucker, and fed fish were less sensitive than those unfed. Effects of age (i.e., 2, 4 or 8 days for flagfish, and 13, 20 or 26 days for white sucker) were less clear-cut. The most sensitive endpoints for each species were a 96-h LC50 of 540 µg a.i./L for 8-day old unfed flagfish and a 96-h LC50 of 1.0 µg a.i./L for 20-day old unfed white sucker (Holdway and Dixon 1988).

Coats and O'Donnell-Jeffery (1979) compared the acute toxicity to rainbow trout fingerlings of technical-grade permethrin (>92% purity) and a formulated emulsifiable concentrate containing 25% permethrin. The formulated product was significantly more toxic, with a 24-h LC50 of 61 µg a.i./L, than the technical-grade permethrin which had a 24-h LC50 of 135 µg a.i./L. The authors speculated that other substances in the formulated product may have facilitated uptake of the permethrin across membranes, thereby enhancing its toxicity (Coats and O'Donnell-Jeffery 1979). Similar results were observed by Paul et al. (2005). Brook trout exposed to technical-grade permethrin (>92% purity) had a 96-h LC50 of 2.86 µg a.i./L whereas those exposed to a formulation containing 31% permethrin and 66% piperonyl butoxide (a synergist) had a significantly lower 96-h LC50 of 0.98 µg a.i./L (Paul et al. 2005). The potential synergistic

effects of additives in permethrin formulations need to be considered when assessing potential risks to aquatic non-target organisms.

Chronic Effects

Only two chronic fish studies were available. Kumaraguru and Beamish (1986) exposed rainbow trout to low concentrations of permethrin (0.65 and 1.25 µg a.i./L) over a 1 to 6 week period in continuous flow tanks. Small (10 g) and large (100 g) fish were used to determine the impact of permethrin on growth rate of the trout. The authors reported a 21-day lowest observed effects concentration (LOEC) of 0.65 µg a.i./L for the small trout, while the large trout were more tolerant. This LOEC value is close to the 96-h LC50 value of 0.62 µg a.i./L reported by Kumaraguru and Beamish (1981). This is likely because the LOEC was derived using 10 g trout and the 96-h LC50 was derived using 1 g trout. As in their earlier acute study (Kumaraguru and Beamish 1981), the authors noted an inverse relationship between toxicity and temperature. Growth reduction relative to controls was observed in the small trout exposed to permethrin at 7°C, but not at 12°C (Kumaraguru and Beamish 1986). No effects of temperature on permethrin toxicity were observed in the larger trout.

Spehar *et al*. (1983) exposed larvae of fathead minnows to permethrin in continuous flow-through exposures for 32 days. A saturated solution of permethrin was used to avoid the need for solvents. Permethrin significantly reduced survival and impaired the swimming ability of 1-day old larvae at a concentration of 1.4 µg a.i./L. Survival of larvae exposed to this concentration was reduced to 37%. Significant reductions in survival were not observed in fish exposed to permethrin concentrations averaging 0.66 µg a.i./L or less. The estimated chronic no observed effects concentration (NOEC) for fathead minnows was 0.66 µg a.i./L while the LOEC was 1.4 µg a.i./L. Embryo hatchability, the percentage of normal larvae at hatch and the growth (weight) of fathead minnows were not decreased at any of the permethrin concentrations tested over the 32-d period.

7.2.1.2 Invertebrates

One of the primary concerns of using pest control products is that non-target organisms can be adversely impacted. This is particularly the case with permethrin and aquatic invertebrate species (Kingsbury 1976; Muir *et al*. 1985; Hill 1985; Kreutzweiser and Sibley 1991; Sundaram 1991). Field studies have demonstrated that where permethrin was intentionally introduced to the aquatic environment (*e.g*., streams, lakes), it has had a major impact on the invertebrate community in that environment. Effects observed include increased invertebrate drift density and invertebrate community changes (Kreutzweiser and Sibley 1991; Werner and Hilgert 1992). In long-term studies with limnocorrals (in situ aquatic enclosures), the diversity of zooplankton present was significantly reduced when exposed to an initial pulse of permethrin at a concentration of 0.5 µg/L (Kaushik et al. 1985). In contrast, however, Jensen et al. (1999) found that permethrin sprayed at ultra-low volumes to wetlands was effective at controlling adult mosquitoes, but had no adverse effects on non-target aquatic organisms. Post-treatment analyses of water samples did not detect any permethrin above the detection limit of 20 µg/L (Jensen et al. 1999). Werner and Hilgert (1992) found that while spray drift from permethrin application to spruce trees resulted in significant mortality to pelagic invertebrates in a nearby stream, there were no adverse effects on benthic invertebrates, trout fry, or periphyton.

Aquatic invertebrates are generally more sensitive to permethrin than freshwater fish species or algae (Appendix A) (Figure 3). Several acute and chronic toxicity studies for freshwater invertebrate species exposed to permethrin are discussed below. A more extensive listing of toxicity studies can be found in Appendix A.

Acute Effects

Acute LC_{50} values for freshwater invertebrates range from 0.17 µg a.i./L for the amphipod (*Gammarus pulex*) (McLoughlin et al. 2000) to 940 µg a.i./L for the beaver-tail fairy shrimp (*Thamnocephalus platyurus*) (Sánchez-Fortún and Barahona 2005).

The most sensitive acute invertebrate studied was the amphipod *Gammarus pulex* (McLoughlin et al. 2000). In a static exposure with daily renewal of test solutions, a 6-d LC50 of 0.17 µg a.i./L was reported. A number of studies have also shown *Daphnia magna* to have a similar level of sensitivity to permethrin. Stratton and Corke (1981) reported 48-h LC50 values of 0.2 and 0.6 µg a.i./L for juvenile and adult *D. magna*, respectively. Similar 48-h LC50 values of 0.43 and 1.06 µg a.i./L were reported in another studies with adult *D. magna* (Stratton and Giles 1990), and Thurston et al. (1985) reported 48-h LC50 values of <1.4 and <2.5 µg a.i./L for juvenile *D. magna*. Other sensitive invertebrates include the adult crayfish *Orconectes immunis* with a 96-h LC50 of <1.2 µg a.i./L (Thurston et al. 1985), larvae of the midge *Tanytarsus dissimilis* with a 48-h LC50 of <2.5 µg a.i./L (Thurston et al. 1985), and nymphs of the damselflies *Enellagma* spp. and *Ishnura* spp. with a 24-h LC50 of 2.9 µg a.i./L (Siegfried 1993).

Abel and Garner (1986) found that exposure of aquatic invertebrates to even a very short pulse of permethrin could result in adverse effects up to two weeks later. For example, with continuous exposure to permethrin at a concentration of 20 µg/L, 50% mortality was observed in the amphipod *Gammarus pulex* after 11.5 hours, but exposure to the same concentration for only 2 hours also resulted in 50% mortality after 14 days. At a concentration of 200 µg/L, exposure for only 3 minutes was sufficient to cause 50% mortality after 14 days.

Several researchers have examined the relative toxicity of technical grade permethrin versus pesticide formulations containing permethrin. Sibley and Kaushik (1991) exposed a number of aquatic invertebrates to an encapsulated formulation of permethrin, called penncapthrin, to determine the difference in toxicity between encapsulated and standard formulations. Several filter feeders (*Simulium vittatum*, *Isonychia bicolour*, *Hydropsyche* spp.) and cladocerans (*Daphnia magna*, *Daphnia pulex*) were exposed in acute toxicity tests. The authors found that the toxicity of penncapthrin was approximately the same as for the standard formulation. There was no significant difference between the toxicity (LC50) of penncapthrin at 96-h and the standard formulation at 72-h. There was a slight delay in mortality on these organisms due to the encapsulation. Control mortality in the penncapthrin tests with *D. pulex* was greater than 10% likely due to the fact that to achieve an LC50 the tests were extended to 96-h. Starvation increased mortality amongst controls (>10%) at this study duration.

Chronic Effects

A limited number of chronic studies were available for invertebrates. Anderson (1982) investigated chronic effects to behaviour and survival of stonefly nymphs (*Pteronarcys dorsata*) and caddisfly larvae (*Brachycentrus americanus*) by exposing the species to permethrin in a flow-through system for up to 28 days. The 21-d LC50 value for *B. americanus* was estimated at

0.17 µg a.i./L. A 21-d LOEC of 0.042 µg a.i./L was reported for immobility in *P. dorsata* at. At this LOEC value, 100% of the stonefly nymphs were immobilized (Anderson 1982). McLoughlin et al. (2000) observed similar sensitivity in the amphipod *Gammarus pulex*, with a 6-d LOEC for reduced feeding rate reported at 0.06 µg a.i./L.

Yasuno *et al*. (1988) examined the impact of permethrin applications on zooplankton in pond enclosures. Two enclosures were initially dosed, from the bottom, with nominal concentrations of 0.75 and 1.5 µg a.i./L of permethrin in an emulsifiable concentrate formulation. A second treatment was conducted 14 days later in which nominal concentrations of 10 and 1.5 µg a.i./L (nominal) were applied to the water surface. Effects of the treatments were compared with a control enclosure over a period of 32 days from the initial application. *Chaoborus flavicans*, the sole predacious zooplankton in the enclosures were found to be extinct at 1.5 µg a.i./L, and suffered severe density decreases at 0.75 µg a.i./L after 120 hours. *Acanthodiaptomus pacificus* had increased population densities at 0.75 and 1.5 µg a.i./L, but suffered 100% mortality at 10 µg a.i./L. *Tropocyclops prasinus* exhibited reduced nauplius density at 0.75 µg a.i./L of permethrin, and at 10 µg a.i./L reduced density was observed in nauplii, copepodids and adults (Yasuno et al. 1988).

7.2.1.3 Algae and Aquatic Plants

Yasuno *et al*. (1988) examined the application of permethrin in the form of an emulsifiable concentrate formulation to pond enclosures, and the impacts to phytoplankton in the enclosures. The phytoplankton community was generally unaffected by nominal water concentrations of up to 10 µg a.i./L. The one exception *Ceratium hirundinella,* a dinoflagellate, showed a significant reduction in mean density compared to controls at a nominal concentration of 0.75 µg a.i./L. Stratton and Corke (1982) examined the toxicity of permethrin and its transformation products towards algae and cyanobacteria. Test cultures included the blue-green algae *Anabaena inaequalis*, *A. cylindrica*, and *A. variabilis*, and the green algae *Chlorella pyrenoidosa* and *Scenedesmus quadricauda*. Permethrin was found to be non-toxic to most of these organisms at the concentrations tested (0 to 1000 µg/L). The one exception was the blue-green algae *A. inaequalis* where an EC50 of 1600 µg a.i./L for growth reduction was reported (Stratton and Corke 1982). A listing of freshwater algae toxicity studies is found in Appendix A.

7.2.1.4 Amphibians

Thurston et al. (1985) exposed tadpoles of the bullfrog (*Rana catesbiana*) to permethrin in flow-through tanks. They observed a 96h LC50 of 115 µg a.i./L. Six species of fish and three invertebrate species were also tested by Thurston et al. (1985) under similar conditions, and of these, the tadpoles were the second least sensitive species, after goldfish. An acute toxicity test has also been conducted with tadpoles of the southern leopard frog (*Rana sphenocephala*) (Bridges et al. 2002). The 96h LC50 for this species was 18.2 µg a.i./L. In comparison with published toxicity data for various fish species, these authors noted that tadpoles were relatively tolerant to permethrin (Bridges et al. 2002). Similarly, Berrill et al. (1993) have also noted that amphibians are relatively tolerant to permethrin, with larvae of the spotted salamander (*Ambystoma maculatum*) observed to be somewhat more sensitive than tadpoles of the wood frog (*Rana sylvatica*), green frog (*Rana clamitans*), northern leopard frog (*Rana pipiens*), or American toad (*Bufo americanus*). Bridges et al. (2002) observed little or no mortality in southern leopard frog tadpoles at any concentration until 96 hours of exposure. Based on this

observation, the authors suggest that tadpoles may only be at risk of dying when exposed to permethrin chronically, rather than just short pulsed exposures (Bridges et al. 2002).

7.2.2 Marine

A review of toxicity studies for marine species is presented below and a summary of all toxicity studies on marine algae, invertebrates and fish is provided in Appendix B.

7.2.2.1 Fish

Acute Effects

Acute 96-h LC50 values for marine fish ranged from 2.2 µg a.i./L for Atlantic silversides (*Menidia menidia*) (Schimmel *et al*. 1983) to 88 µg a.i./L for sheepshead minnow (*Cyprinodon variegatus*) (Borthwick and Walsh 1981) (Appendix B).

Schimmel *et al*. (1983) conducted acute toxicity tests exposing three fish including Atlantic silverside, sheepshead minnow and striped mullet (*Mugil cephalus*) to permethrin under flow-through conditions. The most sensitive species was Atlantic silverside with a 96-h LC50 of 2.2 µg a.i./L, while striped mullet and sheepshead minnow had 96-h LC50 values of 5.5 and 7.8 µg a.i./L, respectively. Other studies reporting acute toxicity at slightly higher concentrations include a 96-h LC50 for Atlantic salmon (*Salmo salar*) at 12 µg a.i./L (McLeese et al. 1980), 96-h LC50 values for sheepshead minnow and Leon Springs pupfish (*Cyprinodon bovinus*) at 17 and 21 µg a.i./L, respectively (Sappington et al. 2001), and 96-h LC50 values of 25.3 and 27.5 µg a.i./L for topsmelt (*Atherinops affinis*) and inland silverside (*Menidia beryllina*), respectively (Hemmer et al. 1992). In comparison, Borthwick and Walsh (1981) reported relatively higher tolerance for sheepshead minnow exposed to permethrin, with a 96-h LC50 of 88 µg a.i./L.

Chronic Effects

Hansen *et al*. (1983) conducted 28-day embryo-larval toxicity tests using the estuarine species sheepshead minnow. Tests were performed in an intermittent-flow system using triethylene glycol as a carrier solvent. Decreased survival was the most sensitive measure of effect in fish exposed to permethrin with NOEC and LOEC values of 10 and 22 µg a.i./L, respectively (Hansen et al. 1983).

7.2.2.2 Invertebrates

Marine invertebrates are generally more sensitive to permethrin than marine fish (Appendix B). Toxicity data for marine invertebrates are only available for acute exposures. Reported acute LC50 values for marine invertebrates ranged from 0.018 µg a.i./L to 8210 µg a.i./L for larvae of the stone crab (*Menippe mercenaria*) and larvae of the San Francisco brine shrimp (*Artemia franciscana*), respectively (Appendix B).

The most sensitive invertebrate study was a static exposure of larval stone crab with a reported 96-h LC50 of 0.018 µg a.i./L (Borthwick and Walsh 1981). A very similar 96-h LC50 of 0.02 µg a.i./L was reported by Schimmel *et al*. (1983) for *Mysidopsis bahia* exposed to permethrin in a flow-through system. Other studies have also reported sensitivity of *Mysidopsis bahia* to permethrin, with 96-h LC50 values of 0.046 and 0.095 µg a.i./L (Borthwick and Walsh 1981;

Cripe 1994). Several other malacostracan crustaceans have also showed acute toxicity at permethrin concentrations within an order of magnitude of the mysid studies. Sand shrimp (*Crangon septemspinosa*) exposed under static-renewal conditions had a 96-h LC50 of 0.13 µg a.i./L (McLeese *et al*. 1980). Two separate studies with pink shrimp (*Penaeus duorarum*), one static and the other with flow-through exposure conditions, reported very similar 96-h LC50 values of 0.17 and 0.22 µg a.i./L, respectively (Cripe 1994; Schimmel *et al*. 1983). Adult lobster (*Homarus americanus*) were somewhat less sensitive with a 96-h LC50 of 0.73 µg a.i./L (McLeese *et al*. 1980). In sharp contrast to these marine invertebrate studies, Sànchez-Fortún and Barahona (2005) reported very low sensitivity of the rotifer *Brachionus plicatilis* and the San Francisco brine shrimp (*Artemia franciscana*). Under static exposures, the 24-h LC50 values for the rotifer and *A. franciscana* were 900 and 8210 µg a.i./L.

7.2.2.3 Algae and Aquatic Plants

Permethrin toxicity data on marine algae were only available for one species, the diatom *Skeletonema costatum*. Walsh and Alexander (1980) reported 96-h EC50 values for reductions in diatom cell count and biomass of 68 and 72 µg a.i./L, respectively. Similar results were reported by Borthwick and Walsh (1981) who observed 96-h EC50 values for growth reduction in two assays with *S. costatum* of 92 and 124 µg a.i./L.

7.3 Terrestrial Plant Toxicity

There is a paucity of data on the toxicity of permethrin to terrestrial plants. Much of the scientific literature for permethrin and plants focuses on permethrin residues in plant tissues (Barakat *et al*. 1987; George 1985; Dejonckheere *et al*. 1982) rather than plant toxicity. Permethrin is an insecticide, and is designed to be applied to plants with a minimum of adverse effects to plant tissue. Therefore, it is not surprising that few data are available for plant toxicity.

7.3.1 Crop Toxicity

7.3.1.1 Cereals, Tame Hays, and Pastures

Only one study was found describing the toxicity of permethrin on cereals, tame hays or pastures. Barnard et al. (1989) examined the effects of permethrin on corn (*Zea mays*). A foliar application of permethrin was applied at a rate of 0.15 kg/ha to plots of corn in 1979, 1984 and 1985. (Note: it was not indicated whether this rate refers to active ingredient or a formulation.) In the 1979 test, permethrin appeared to cause a slight decrease in plant height (though it was not reported whether this was statistically significant), with a mean of 180 cm compared to a mean height in control plots of 188 cm. The yield of forage in the permethrin-treated plot, however, was increased by 0.6 tonnes of dry matter per hectare, indicating a positive effect of the permethrin application. In the 1984 and 1985 tests, no effects of permethrin on yield were observed.

7.3.1.2 Other Crops

In a study by Bélanger and Hamilton (1979), permethrin was applied to three vegetable species, carrots (*Daucus carota*) onions (*Allium cepa*), and lettuce (*Lactuca sativa*) in organic soil to determine soil residues and translocation of these residues into the plant species. Permethrin was

applied in a granular formulation at 3 cm depth at nominal application rates of 0.56 and 1.12 kg a.i./ha. Control plots received no permethrin. Yields of both carrot and lettuce were unaffected by the permethrin application at either rate. Onion yield was significantly lower at both test concentrations compared to the controls.

In another study, an emulsifiable concentrate formulation of permethrin was applied to plots of lettuce at the recommended rate of 0.22 kg a.i./ha, as well as at double the rate (i.e., 0.44 kg a.i./ha) (Toscano et al. 1982). At both application rates, photosynthesis and stomatal conductance were significantly decreased when measured at one day post-treatment. By 8 days post-treatment, stomatal conductance in the permethrin-treated plants (23 cm diffusion/second) was still significantly reduced from controls (31 cm diffusion/second), but photosynthesis was not. Both of these processes are directly related to plant growth and productivity (Toscano et al. 1982). However, it is not known whether a 26% reduction in stomatal conductance for 8 days would translate into any adverse effect on growth or yield.

Klein and Samek (2002) examined the mitotic effects of Ambush 25EC, an emulsifiable concentrate containing 25% permethrin, on root meristem cells of pea (*Pisum sativum*) seedlings. Seedling roots were treated with the pesticide formulation at concentrations of 0.02 and 0.2% for 4 or 8 hours. After 8 hours at the highest dose, which represents an application rate 10 times higher than rates used in agricultural practices, Ambush produced a small decrease in the mitotic index. This suggests that there may be a slight potential for genomic and chromosomal mutations to occur in agricultural crops and wild plants growing near fields sprayed with permethrin (Klein and Samek 2002). Whether this would have any impact on plant growth or yield is questionable.

7.4 Livestock Toxicity

7.4.1 Mammals

Mammalian species are known to be generally insensitive to concentrations of permethrin in the environment (IPCS 1990). In fact, some formulations of permethrin are specifically intended for application to mammals. For example, permethrin is routinely used as the active ingredient in cattle and horse ear tags and spray washes to aid in the control of biting insects (Morgan and Bailie 1980; Quisenberry and Strohbehn 1984). Permethrin is also used as an active ingredient in many flea and tick sprays for household pets. There are even intended uses that result in direct contact with humans, such as treatment of military clothing and mosquito netting (IPCS 1990). Mammals quickly metabolize permethrin and eliminate it through the feces, urine, and milk (Hunt and Gilbert, 1977). Ivie and Hunt (1980) analysed the excretions of lactating goats exposed to permethrin using thin layer chromatography and mass spectrophotometry. They reported 26 transformation products of permethrin that arose through the hydrolysis of the permethrin ester linkage. Morgan and Bailie (1980) used permethrin in direct sprays to control biting insects in a herd of dairy cows. The effect of the permethrin spray on milk production was monitored. The authors found that milk production increased in the sprayed cattle relative to control cattle. Similarly, Quisenberry and Strohbehn (1984) found that when beef cattle were treated with permethrin-impregnated ear tags, their nursing calves showed greater weight gains than calves of untreated cows.

Toxicity of permethrin has been tested on laboratory mammals. Glickman et al. (1982) administered technical permethrin (93% purity with *cis*:*trans*, 40:60), *cis*-permethrin (99%

purity) and *trans*-permethrin (99% purity) both intravenously and intraperitoneally to mice at various concentrations to determine the median lethal dose. The 24-h LD50 values for intravenous (iv) injections were approximately 10-fold lower than those for the intraperitoneal injections. With iv injection, the 24h LD50 values for the technical, *cis*- and *trans*-permethrin were 31, 17, and >135 mg/kg, respectively (Glickman et al. 1982). It is interesting to note that in mice the *trans*- isomer was considerably less toxic than the *cis*- isomer, whereas in parallel tests with rainbow trout the two permethrin isomers showed similar levels of toxicity.

7.4.2 Birds

Avian toxicity studies have shown that permethrin has very low toxicity to birds, with birds being even less sensitive than mammals (Hill 1985; IPCS 1990). LD50s have been reported at greater than 3000 mg/kg body weight and dietary toxicity at >5000 mg/kg diet (IPCS 1990). Tomlin (2000) lists oral LD50s for chickens (>3000 mg/kg), mallard ducks (>9800 mg/kg) and Japanese quail (>13,500 mg/kg). The U.S. EPA Pesticide Effects Database (U.S. EPA 2004) contains data on several studies for mallard ducks (*Anas platyrhynchos*), ring-necked pheasant (*Phasianus colchicus*) and bobwhite quail (*Colinus virginianus*). One study reported a 20-week LOEL (the specific effect was not indicated) of 500 mg/kg for a mallard duck. For all other avian studies in the database, LOELs could not be determined as effects were not observed at the highest concentrations tested.

Hoffman and Albers (1984) examined the toxicity of permethrin to mallard eggs by dipping the eggs in various concentrations of Pounce® 3.2 EC, an emulsifiable concentrate containing 38.4% permethrin. They determined the 18-day LC50 to be >40 lb pesticide/A (i.e., >45 kg/ha) at 100 gal/A (935 L/ha). The authors noted that this LC50 was greater than 100 times the field level of application for Pounce® (Hoffman and Albers 1984).

Kapoor et al. (1988) studied the effects permethrin on white leg horn chicks fed a vitamin A-deficient diet. Daily, the chicks were fed technical grade (99% purity) permethrin dissolved in ground nut oil at concentrations ranging from 10 to 200 mg a.i./kg body weight. After 6 days of exposure, doses of 50 mg a.i./kg body weight and higher resulted in significant induction of hepatic cytochrome P-450, and at doses of 100 mg a.i./kg body weight and higher there was significant induction of NADPH-cytochrome *c* reductase. However, body weight gains and liver weights in all treatments were not significantly different from the controls.

These data demonstrate that bird species are very insensitive to permethrin.

7.5 Toxicity-Modifying Factors

Temperature

Permethrin lethality to fish has been noted to vary inversely with water temperature and body weight (Kumaraguru and Beamish 1981, 1986). Through exposure of rainbow trout to permethrin at various temperatures, Kumaraguru and Beamish (1981) found that the toxicity of permethrin varied inversely with temperature. The 96-h LC50 at 5°C to 10°C was 0.62 µg a.i./L to 0.69 µg a.i./L. Between 10 and 15°C, the 96-h LC50 increased to 3.17 µg a.i./L (Kumaraguru and Beamish 1981). Later, in a chronic study, Kumaraguru and Beamish (1986) again noted an

inverse relationship between toxicity and temperature. Small (10 g) trout exposed to permethrin experienced growth reduction at 7°C, but not at 12°C. An effect of size was also noted, as no effects of temperature on permethrin toxicity were observed in large (100 g) trout (Kumaraguru and Beamish 1986). Most pyrethroids have been noted to be more toxic to insects at lower temperatures, however, reported effects of temperature on toxicity to fish are much more variable in the literature (Hill 1985). From the permethrin toxicity data listed in Appendix A, no clear relationship with temperature is seen.

Suspended and Bed Sediments

Due to the strong adsorption of permethrin to particulate matter, the presence of either bed sediments, or suspended sediments in the water column can reduce the bioavailability, and therefore the toxicity of permethrin. Unpublished data from studies by ICI Plant Protection Division (as cited in Hill 1985) demonstrate this effect. *Daphnia magna*, the mayfly *Cleoeon dipterum* and the isopod *Asellus aquaticus* were exposed to permethrin in water only, in water with a bottom layer of sediment, and in water with suspended sediment. The treatments with sediment were conducted by mixing the permethrin into the sediment before addition of the water. In the treatment with water only, the 72-h EC50 values for *D. magna*, *C. dipterum* and *A. aquaticus* were 3.4, 0.027 and 0.085 µg a.i./L, respectively. In the presence of suspended sediment particles, the EC20 values were approximately 200 times higher, at 810, 8.4 and 13 µg a.i./L for *D. magna*, *C. dipterum* and *A. aquaticus*, respectively. EC50 values for treatments with bed sediments were not significantly different from the treatments with suspended sediments. Another study by ICI was conducted with *D. magna* in which permethrin was applied to the water surface in treatments with water only or water with bottom sediments (Hill 1985). In this case, the presence of the sediments was again found to decrease bioavailability, though not to as large an extent as when the permethrin was added to the sediments. The 48-h EC50 of 2.5 µg a.i./L for surface-applied permethrin in the water plus bed sediments treatment was 5-fold higher than the water only treatment (0.5 µg a.i./L).

7.6 Toxicity of Transformation Products

Major transformation products of permethrin are much less toxic than the parent compound to invertebrates and fish. In studies with *Daphnia magna*, three hydrolysis products of permethrin, DVAC, 3-phenoxybenzyl alcohol and 3-phenoxybenzoic acid, had 48h EC50 values of 128 000, 10 000, and 85 000 µg a.i./L, respectively (Hill 1985). These EC50 values are five or more orders of magnitude greater than 48h LC50 values for permethrin which range from 0.2 to 2.5 µg a.i./L (Stratton and Corke 1981; Thurston et al. 1985). Similar results have been found with fish. Zitko et al. (1977) found that DVAC and 3-phenoxybenzyl alcohol were not lethal to juvenile Atlantic salmon (*Salmo salar*) at the highest concentration they tested of 5000 µg a.i./L. In other assays DVAC, 3-phenoxybenzyl alcohol and 3-phenoxybenzoic acid were three or more orders of magnitude less toxic to various fish species than permethrin, with 96h LC50 values greater than 3000 µg a.i./L (Hill 1985).

Unlike fish and invertebrates, there is evidence to suggest that some of the transformation products of permethrin are more toxic to algae than the parent compound. This difference in the effects of transformation products among the taxa likely reflects a different mode of action in algae. In particular, some of the phenoxy derivatives of permethrin (i.e., 3-phenoxybenzyl alcohol, 3-phenoxybenzaldehyde, and 3-phenoxybenzoic acid) have shown greater toxicity than permethrin to the algae *Anabaena cylindrica*, *Chlorella pyrenoidosa* and *Scenedesmus*

quadricauda (Stratton 1981). The EC50 values for inhibition of photosynthesis by these three compounds ranged from as low as 2000 µg a.i./L, while EC50 values for permethrin were all >100 000 µg a.i./L. Two acids, 3-hydroxybenzoic acid and benzoic acid, also showed greater toxicity than permethrin. Other derivatives in the hydroxy and benzyl series (e.g., 3-hydroxybenzyl alcohol, 3-hydroxybenzaldehyde and benzyl alcohol), however, were not particularly toxic (Stratton 1981).

Although some transformation products are more toxic than permethrin to algae, effects occur at concentrations that are still orders of magnitude higher than concentrations of permethrin that are toxic to invertebrates and fish. Therefore, water quality guidelines for permethrin that are protective of invertebrates will also protect against effects of resulting transformation products on algae.

8.0 WATER QUALITY GUIDELINE DERIVATION

The Canadian Water Quality Guidelines for permethrin were derived in accordance with "A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life" (CCME 1991) and "Protocols for Deriving Water Quality Guidelines for the Protection of Agricultural Water Uses (Irrigation and Livestock Water)" (CCME, 1993). The following sections describe the derivation process for each of the guidelines.

8.1 Protection of Freshwater Aquatic Life

The minimum data requirements for the derivation of a full freshwater guideline, as outlined in the protocol (CCME 1991), were not met for permethrin. Only one chronic primary fish study was available (Spehar et al. 1983). Data on two chronic primary invertebrate species were available (Anderson 1982), but the two species (*Brachycentrus americanus* and *Pteronarcys dorsata*) were both from the same class (Insecta). There were no algae studies of primary quality available. The data requirements for an interim water quality guideline, which allow for both acute or chronic studies of primary or secondary quality, were easily met by the available data. Therefore, an interim freshwater quality guideline was derived as described below.

8.1.1 Derivation of Interim Freshwater Guideline

The most sensitive species identified from the literature reviewed is the stonefly Pteronarcys dorsata (Appendix A). Anderson (1982) exposed nymphs of P. dorsata to technical grade permethrin for a period of 28 days, without the addition of any formulants or solvents, under flowthrough conditions. Unfiltered Lake Superior water was used for all rearing and testing. This water was kept at a temperature of 15°C, the pH ranged from 7.6 to 7.8, water hardness and alkalinity were 46-48 and 42-44 mg $CaCO_3$/L, respectively, and dissolved oxygen levels were maintained at greater than 95% saturation. Two replicate exposure chambers were used for each of the five test concentrations and control, with 10 nymphs placed in each replicate chamber. Samples for permethrin analysis were collected from each of the exposure tanks once a week and were measured by gas chromatography. Percent recovery for the permethrin water analyses was 85%, and all reported values were based on measured concentrations corrected for recovery. The measured test concentrations were 0.029, 0.042, 0.12, 0.21 and 0.43 µg a.i./L. During the exposure period, the nymphs were examined daily for behavioural effects or death. No mortality was observed in the controls. Behavioural effects identified in P. dorsata started with a loss of coordinated movement in which the legs of the nymphs moved in a random manner and the

animal often twisted and twirled as it tried to move. In the next stage, there was a loss of equilibrium in which the nymphs lay on their side or top and could not right themselves. A 21-d LOEC of 0.042 µg a.i./L was reported. At this concentration, immobility was observed in 100% of the population. Immobilization at this concentration occurred sometime between 14 and 21 days. The authors noted, however that the prolonged immobilization did not often result in death, with the maximum death at any concentration being three organisms. This study was classified as being of primary quality for guideline derivation.

Several other primary and secondary studies have reported effect concentrations within the same range as the LOEC for *P. dorsata*. McLoughlin et al. (2000) reported a 6-d LOEC for reduced feeding rate in adults of the amphipod *Gammarus pulex* at 0.06 µg a.i./L. The 6-d LC50 for *G. pulex* was 0.17 µg a.i./L (McLoughlin et al. 2000), as was the 21-d LC50 for larvae of the caddisfly *Brachycentrus americanus* (Anderson 1982). A 48-h LC50 reported for juvenile Daphnia magna was 0.2 µg a.i./L (Stratton 1981; Stratton and Corke 1981).

According to the protocol (CCME 1991), a guideline is preferentially derived using the most sensitive chronic study available. The *P. dorsata* study by Anderson (1982) was selected as the critical study. Because this is a chronic (21-d) study, a safety factor of 0.1 was applied, as per the protocol (CCME 1991). The interim freshwater aquatic life guideline for permethrin was therefore calculated as follows:

$$IWQG_{FAL} = LOEC \times SF$$

$$= 0.042 \times 0.1$$

$$= 0.0042 \approx 0.004 \text{ µg a.i./L}$$

where,

$IWQG_{FAL}$ = Interim Water Quality Guideline for Freshwater Aquatic Life
SF = Safety Factor

Therefore, the interim water quality guideline for the protection of freshwater aquatic life is 0.004 µg a.i./L.

Figure 3 presents a selection of the most sensitive freshwater toxicity data that were available and illustrates where the critical study and resulting guideline values fall with respect to the distribution of other sensitive endpoints.

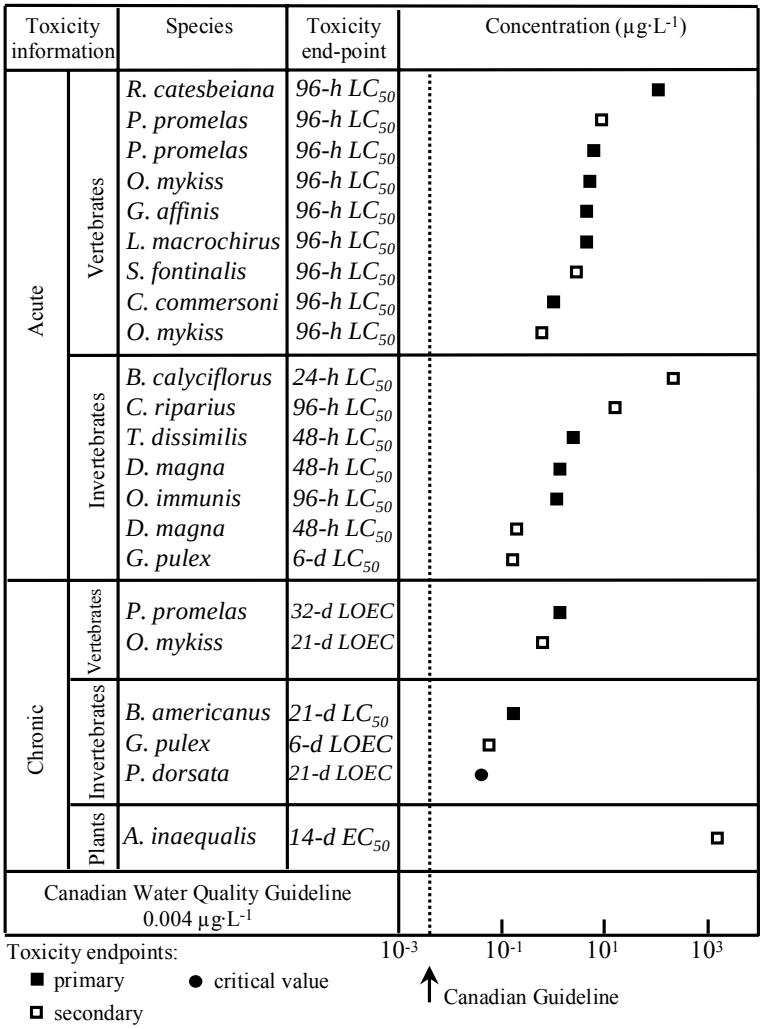

Figure 3 Select freshwater toxicity data for permethrin

The freshwater guideline for permethrin is based on a chronic exposure study. Given the environmental fate characteristics of permethrin (*e.g.*, rapid transformation and degradation in water, strong adsorption to sediment) and its method of application (sprayed on crops typically once or twice in a season) a chronic exposure scenario is less likely than an acute exposure for aquatic species. Uses in which permethrin may be applied more frequently, such as flea and tick control on pets, or control of household pests, are also not likely to result in chronic exposures to aquatic organisms due to the low risk for surface water contamination through these applications. Therefore, it could be argued that it would be more appropriate and relevant to derive the guideline based on an acute toxicity test. However, endpoints for some acute studies were within less than an order of magnitude of the most sensitive chronic study. In several studies, it was also shown that even with pulsed exposures that lasted only an hour in duration, effects were still seen in the exposed organisms several days later. Therefore, despite the greater likelihood of acute exposures occurring in the aquatic environment, it is not anticipated that this freshwater guideline based on a chronic study will be overly conservative.

8.2 Protection of Marine Aquatic Life

The minimum data requirements for the derivation of a full marine water quality guideline have not been met according to the protocol (CCME 1991). No chronic, primary studies are available for marine fish, invertebrates or plants/algae. The minimum data requirements for an interim marine water quality guideline, which allow for the use of acute or chronic data, and data of primary or secondary quality, have been met. Therefore, an interim marine water quality guideline is derived below.

8.2.1 Derivation of Interim Marine Guideline

Of the studies identified, the most sensitive species to permethrin was the stone crab, *Menippe mercenaria* (Appendix B). Borthwick and Walsh (1981) exposed larvae of *M. mercenaria* to permethrin (93% purity) for an acute period of 96 hours under static conditions. It was not stated whether any solvents were used. Water, at a salinity of 20‰, was kept at a temperature of 25°C. The study did not report the number of replicates used, nor whether there was any control mortality, but did state that it followed a standard method of the American Society for Testing and Materials (ASTM). Effect values reported were based on nominal concentrations, as water samples from the test vessels were not analysed for permethrin. A 96-h LC50 of 0.018 µg a.i./L was reported. This study was classified as being of secondary quality for guideline derivation.

The second-most sensitive study had a very similar LC50 value. Schimmel *et al*. (1983) exposed newly hatched mysid individuals (≤24hrs old) to permethrin (93% purity), using triethylene glycol as a solvent. The mysids were exposed in flow-through chambers in accordance with a test protocol described by ASTM. Four replicate exposure chambers were used for each of the test concentrations plus solvent control and seawater control, with 5 mysids placed in each replicate chamber. Temperature was maintained at 26 °C, and salinity at 25‰. In calculating the LC50, Abbott's correction was used to correct for control mortality which was ≤10% (Schimmel *et al*. 1983). The 96-h LC50 for *M. bahia* was reported at a nominal concentration of 0.02 µg/L. This study was classified as being of primary quality.

Two other studies with juvenile *M. bahia* also reported median lethal concentrations in a similar range. A 96-h LC50 of 0.046 µg a.i./L was reported by Borthwick and Walsh (1981), and Cripe (1994) reported a 96-h LC50 of 0.095 µg a.i./L. Both of these studies were of secondary quality.

According to the protocol (CCME 1991), in the absence of a sensitive chronic LOEC with a nonlethal endpoint, a guideline is derived using a sensitive acute median lethal or median effective concentration. This short-term LC50 or EC50 is then converted to a long-term concentration through the use of either an acute/chronic ratio, or a universal application factor.

Although the most sensitive endpoint was the 96-h LC50 of 0.018 µg a.i./L for *Menippe mercenaria* (Borthwick and Walsh 1981), the 96-h LC50 of 0.02 µg a.i./L for *Mysidopsis bahia* (Schimmel et al. 1983) was chosen as the critical study for guideline derivation. Both studies would result in approximately the same guideline value, however, the *M. bahia* study was considered superior for a number of reasons. Unlike the *M. mercenaria* study, the *M. bahia* study used a flow-through exposure, and provided more experimental details, such as numbers of replicates, control mortality, and solvents used. No appropriate acute/chronic ratio studies were available for permethrin. An acute-chronic ratio of 6.7 was calculated for use in deriving the Quebec water quality criteria for permethrin (Guay et al. 2000); however, because this value was

based on studies with freshwater organisms (*Daphnia magna* and fathead minnow), application of the acute-chronic value to marine data was deemed inappropriate. Therefore, a universal application factor was applied. In accordance with the protocol (CCME 1991), the recommended application factor is 0.05 because permethrin is nonpersistent in water ($t_{1/2}$<8 weeks). The interim marine aquatic life guideline for permethrin is therefore calculated as follows:

$$IWQG_{MAL} = LC_{50} \times AF$$

$$= 0.02 \times 0.05$$

$$= 0.001 \text{ µg a.i./L}$$

where,

$IWQG_{MAL}$ = Interim Marine Water Quality Guideline for the Protection of Aquatic Life
AF = Application factor

Therefore, the interim marine water quality guideline for the protection of aquatic life is 0.001 µg a.i./L.

Figure 4 presents a selection of the most sensitive marine toxicity data that were available and illustrates where the critical study and resulting guideline values fall with respect to the distribution of other sensitive endpoints.

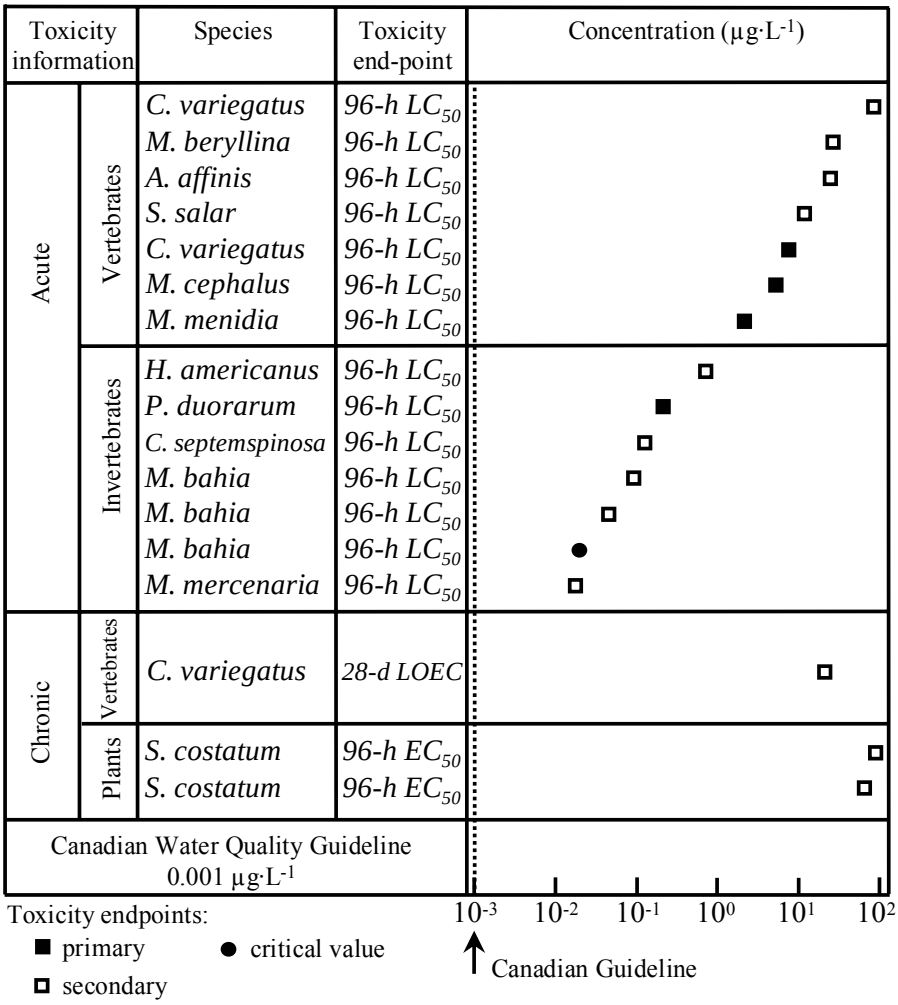

Figure 4 Select marine toxicity data for permethrin

8.3 Protection of Irrigation Water

There are insufficient data on the toxicity of permethrin to cereal, tame hay, pasture crops, or other crops to derive either a full or interim water quality guideline for the protection of irrigation water as outlined in the protocol (CCME 1993). Of the four studies found, two (Toscano et al. 1992; Klein and Samek 2002) measured unconventional endpoints for which the long-term ecological relevance is unknown, and another (Barnard et al. 1989) was of unacceptable quality due to factors such as the lack of replication and statistical analyses, and concurrent testing of another variable (nitrogen).

To derive an interim guideline, two studies on a cereal, tame hay, or pasture crop other than corn, and one study on another crop species from one of the following groups: Leguminosae, Compositae, Cruciferae, Cucurbitaceae, Solanaceae, Umbilliferae, or Chenopodiaceae, would be required.

The effects of permethrin applied at a rate of 0.56 kg a.i./ha on the yield of onions, as observed by Bélanger and Hamilton (1979) suggests that adverse effects could occur in crops if permethrin is present at sufficiently high concentrations, for example, due to a spill. For most registered uses of permethrin on crops in Canada, application rates are less than 0.2 kg a.i./ha (see Chapter 3).

Given the relative insensitivity of plants to permethrin compared with invertebrates, and hence its recommended use as an insecticide for application to various crops, it is not surprising that few studies were available that examine the toxicity of permethrin to terrestrial plants. At concentrations that are likely to occur in irrigation water from normal use of permethrin, it is doubtful that adverse effects would occur in plants. Nonetheless, there may be situations in which an irrigation guideline for permethrin would be useful, for example in the event of a spill.

8.4 Protection of Livestock Water

A water quality guideline for the protection of livestock water is not recommended for permethrin. There are insufficient data available on the toxicity of permethrin to mammalian livestock species to derive either a full or interim water quality guideline for the protection of livestock water as outlined in the protocol (CCME 1993). An adequate number of toxicity studies on avian species were found, however an additional study on a mammalian livestock species would be required to derive an interim guideline. Apart from a study on mice, the only mammalian studies found were not actually investigating adverse effects of permethrin on livestock, but instead reported indirect positive effects due to control of insect pests by the pesticide.

Even if the minimum data requirements could be met, a livestock watering guideline for permethrin would likely not be useful. Both mammals and birds are generally considered insensitive to permethrin, which has always been one of the main selling features of this active ingredient. Therefore, under typical application rates of permethrin, it is doubtful that concentrations that are likely to occur in water used for watering of livestock would cause adverse effects.

8.5 Data Gaps and Research Recommendations

Although there is a fairly large body of toxicity data available for permethrin, much of this data is based on acute studies, and many of these studies are not of primary quality. In particular, the dataset for freshwater life is lacking in chronic primary studies on algae, and invertebrates from classes other than Insecta. A chronic primary study on a freshwater fish other than fathead minnow is also needed. The dataset for marine life is completely lacking in chronic primary studies for fish, invertebrates and algae.

Additional permethrin toxicity data were located on both freshwater and marine organisms in the U.S. EPA's Pesticide Effects Database. This database, developed by the Ecological Fate and Effects Division of the Office of Pesticide Programs, contains ecotoxicity data for registered pesticides used in the U.S., including data on active ingredients, metabolites, and multi-ingredient formulations (U.S. EPA 2004). Information in the database was compiled from studies reviewed by U.S. EPA in conjunction with pesticide registration or re-registration and studies performed by U.S. EPA, USDA and USFWS laboratories that have been reviewed by Ecological Effects Branch biologists and judged acceptable for use in the ecological risk

assessment process. Unfortunately, many of these data came from U.S. EPA pesticide registration packages or sources that are considered confidential business information or generally are not made readily available to the public. It is possible that access to these data could be obtained through submission of a U.S. Freedom of Information Act request. Appendix C contains a table of all of the Pesticide Effects Database data for permethrin.

The U.S. EPA's Pesticide Effects Database was reviewed to determine whether it contained any additional data that could impact the calculation of the Canadian water quality guideline. There was only one data point found that was lower than the critical study identified through our literature search. This was a 96-h EC50 (effect not specified) for *Daphnia magna* of 0.039 µg a.i./L from a study conducted in the early 1970s. This is very similar to the critical value used to derive the freshwater guideline, which was a 21-d LOEC for immobilization of the stonefly *Pteronarcys dorsata* at 0.042 µg a.i./L (Anderson 1982), and therefore would not result in any change to the freshwater guideline.

An assessment was also made to determine whether any of the studies in the U.S. EPA database would address data gaps for upgrading the interim guidelines to full status. For freshwater species, there were three chronic studies on *Daphnia magna* that, if classified as being of primary quality, could fulfill the need for an additional chronic invertebrate study. The U.S. EPA had classified one of these studies as being a "core" study, and therefore it might also meet the definition of a primary study under the CCME protocol (CCME 1991). The other two *D. magna* studies, however, were classified by the U.S. EPA as being "supplementary" and "invalid", so would likely not be of primary quality. For marine species, there was one chronic study on sheepshead minnow that could potentially fulfill the requirement for a chronic primary fish study. The U.S. EPA had classified it as a "supplementary" study though, suggesting that it might not be of primary quality. Irregardless, even with these additional data, both the freshwater and marine guidelines could not be upgraded from interim to full due to other remaining data gaps.

Insufficient data were available to derive water quality guidelines for irrigation and livestock watering. Although it would be helfpul to have permethrin guidelines for agricultural water uses, these data gaps are not seen as a high priority to fill. Due to the very low toxicity of permethrin to plants, mammals and birds, it is not likely that permethrin will be present in agricultural water at concentrations that would cause adverse effects to these organisms.

9.0 GUIDANCE ON APPLICATION OF THE GUIDELINES

9.1 General Guidance on the Use of Guidelines

Canadian Water Quality Guidelines (CWQGs) are numerical concentrations or narrative statements that are recommended as levels that should result in negligible risk of adverse effects to aquatic biota. As recommendations, the CWQGs are not legally enforceable limits, though they may form the scientific basis for legislation or regulation at the provincial, territorial, or municipal level. CWQGs may also be used as benchmarks or targets in the assessment and remediation of contaminated sites, as tools to evaluate the effectiveness of point-source controls, or as "alert levels" to identify potential risks.

CWQG values are calculated conservatively, such that they protect the most sensitive life stage of the most sensitive aquatic life species over the long term. Hence, concentrations of a

parameter that are less than the applicable CWQG are not expected to cause any adverse effect on aquatic life. Concentrations that exceed the CWQGs, however, do not necessarily imply that aquatic biota will be adversely affected, or that the water body is impaired; the concentration at which such effects occur may differ depending on site-specific conditions. Where the CWQGs are exceeded, professional advice should be sought in interpreting such results. As with other CWQGs, the guidelines for permethrin are intended to be applied towards concentrations in ambient surface waters, rather than immediately adjacent to point sources such as municipal or industrial effluent outfalls.

9.2 Detection Limits

The recommended guidelines for permethrin may be lower than the detection limits of some analytical methods. Therefore, in order to determine whether concentrations of permethrin in water samples exceed the guidelines or not, it is recommended that a method with a detection limit of 0.001 µg/L or lower (e.g., Bonwick et al. 1995) be used.

9.3 Site-Specific Considerations

In comparing analytical measurements of water samples with the Canadian Water Quality Guidelines, it is generally recommended that total concentrations from unfiltered water samples be determined. It should be noted, however, that because permethrin is practically insoluble in water and has a high tendency to adsorb to particulate matter, the presence of suspended sediments is likely to reduce the bioavailability of permethrin. Therefore, at sites where there are high levels of particulate matter in the water column, if measured concentrations of permethrin exceed the CWQG, development of a site-specific guideline might be considered. For more information on approaches for the development of site-specific guidelines, refer to CCME (2003).

9.4 Best Management Practices

Direct application of permethrin to surface waters is not permitted in Canada. However, detectable concentrations of permethrin in aquatic systems can result from runoff and/or spray drift. Application instructions and mitigation measures, such as spray buffer zones, specified on product labels must always be followed. In addition, the use of best management practices can further reduce the potential contamination of aquatic systems by pesticides.

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Appendix A. SUMMARY OF FRESHWATER TOXICITY STUDIES FOR PERMETHRIN

Organism	Life Stage	Endpoint	Effect conc. (µg a.i./L)	% a.i.	Test Type[a]	Carrier or formulant	Temp (°C)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank[b]
Algae / Plants												
Anabaena cylindrica (Blue-green algae)	NA	14d-NOEC (growth)	>10000	86.6	S, N	acetone	20	NR	NR	NR	Stratton and Corke 1982	U
Anabaena inaequalis (Blue-green algae)	NA	14d-EC50 (growth)	1600	86.6	S, N	acetone	20	NR	NR	NR	Stratton 1981; Stratton and Corke 1982	2
Anabaena variabilis	NA	14d-NOEC (growth)	>10000	86.6	S, N	acetone	20	NR	NR	NR	Stratton and Corke 1982	U
Ceratium hirundinella (Dinoflagellate)	NA	120h-LOEC (reduced density)	0.75[c]	NR	Field, N	Emulsifiable concentrate	23-30	0.03 - 8	NR	NR	Yasuno et al. 1988	U
Chlamydomonas reinhardtii (Green algae)	NA	72h-EC100 (growth)	391000	93	S, N	ethyl alcohol	25	NR	NR	NR	Gandhi et al. 1988	U
Chlamydomonas reinhardtii (Green algae)	NA	72h-NOEC (growth)	4700	93	S, N	ethyl alcohol	25	NR	NR	NR	Gandhi et al. 1988	U
Chlamydomonas reinhardtii (Green algae)	NA	2h-NOEC (zygote formation)	>0.001 mol/L	94	S, N	Ethyl alcohol	NR	NR	NR	NR	Netrawali et al. 1986	U
Chlorella pyrenoidosa (Green algae)	NA	14d-NOEC (growth)	>10000	86.6	S, N	acetone	20	NR	NR	NR	Stratton and Corke 1982	U
Scenedesmus quadricauda (Green algae)	NA	14d-NOEC (growth)	>10000	86.6	S, N	acetone	20	NR	NR	NR	Stratton and Corke 1982	U
Invertebrates												
Acanthodiaptomus pacificus (Calanoid copepod)	NR	120d-LC100	10[c]	NR	Field, N	Emulsifiable concentrate	23-30	0.03 - 8	NR	NR	Yasuno et al. 1988	U
Aedes aegypti (Yellowfever mosquito)	larvae	48h, 84h-LC50	0.69 – 1.70[d]	NR	S, M	Ambush® formulation	20	NR	NR	NR	Helson et al. 1986	U
Alonella spp. (Cladoceran)	various	48h-LC50	4.0[d]	42	S, N	Spartan® formulation	20-22	6.6-7.5	26-28	8.0-8.5	Naqvi & Hawkins 1989	U
Baetis rhodani (Mayfly)	nymph	24h[f]–LC90-95	1.0[e]	NR	F, N	NR	17.5	NR	NR	NR	Muirhead-Thomson 1978	U

Brachionus calyciflorus (Rotifer)	larvae	24h-LC50	220	NR	S, N	acetone	25	NR	NR	7.4	Sánchez-Fortún & Barahona 2005	2
Brachycentrus americanus (Caddisfly)	larvae	21d-LC50	0.17	TG	F, M	No	15	95% saturation	46-48	7.6-7.8	Anderson 1982	1
Brachycentrus subnubilis (Caddisfly)	larvae	24h[f]-LC90-95	1.0[e]	NR	F, N	NR	17.5	NR	NR	NR	Muirhead-Thomson 1978	U
Ceriodaphnia dubia (Water flea)	juvenile	48h-LC50	0.55[e]	25.6	S, N	Ambush® formulation	25	NR	NR	NR	Mokry & Hoagland 1990	U
Chaoborus flavicans (Phantom midge)	larvae	120h LOEC (reduced density)	0.75[c]	NR	Field, N	Emulsifiable concentrate	23-30	0.03 - 8	NR	NR	Yasuno et al. 1988	U
Chironomus plumosus (Midge)	3rd instar	48h-EC50	0.56	91	S, NR	NR	22	NR	42	7.4	Mayer & Ellersieck 1986	U
Chironomus riparius (Midge)	juvenile / larvae	96h-LC50	16.6	NR	S, N	NR	20	NR	NR	NR	Ibrahim et al. 1998	2
Chironomus riparius (Midge)	larvae	96h-LC50	2.89[c]	NR	S, N	Picket® formulation	20	NR	NR	NR	Conrad et al. 1999	U
Culex pipiens quinquefasciatus (Southern house mosquito)	larvae	24h-LC50	1.40	TG	S, N	acetone	NR	NR	NR	NR	Mulla et al. 1978	U
Cypria spp. (Ostracod)	various	48h-LC50	5.0[d]	42	S, N	Spartan® formulation	20-22	6.6-7.5	26-28	8.0-8.5	Naqvi & Hawkins 1989	U
Daphnia magna (Water flea)	juvenile	48h-LC50	1.25[e]	25.6	S,N	Ambush® formulation	25	NR	NR	NR	Mokry & Hoagland 1990	U
Daphnia magna (Water flea)	juvenile	48h-LC50	0.2	86.6	S, N	acetone	20	NR	NR	NR	Stratton 1981; Stratton and Corke 1981	2
Daphnia magna (Water flea)	adult	48h-LC50	0.6	86.6	S, N	acetone	20	NR	NR	NR	Stratton 1981; Stratton and Corke 1981	2
Daphnia magna (Water flea)	juvenile	48h-LC50	<1.4	93	F, M	dimethylformamide	21	8.86	NR	8.06	Thurston et al. 1985	1
Daphnia magna (Water flea)	juvenile	48h-LC50	<2.5	93	F, M	dimethylformamide	20.8	8.48	NR	8.02	Thurston et al. 1985	1
Daphnia magna (Water flea)	Adult	48h-LC50	0.43, 1.06	86.6	S, N	acetone	25	NR	NR	NR	Stratton & Giles 1990	2
Daphnia magna (Water flea)	1st instar	48h-EC50	1.26	91	S, NR	NR	18	NR	42	7.4	Mayer & Ellersieck 1986	U
Daphnia magna (Water flea)	juvenile	96h-LC50	0.59-21.81[d]	NR	S, N	Penncapthrin encapsulated formulation	14	NR	NR	7.8	Sibley & Kaushik 1991	U
Daphnia magna (Water flea)	juvenile	72h-LC50	6.8-22.57[d]	50	S, N	emulsifiable concentrate	14	NR	NR	7.8	Sibley & Kaushik 1991	U

Daphnia magna (Water flea)	24h old	40d-LOEC (time to first brood)	5.0[d]	NR	S, N	Penncapthrin encapsulated formulation	NR	NR	NR	NR	Sibley & Kaushik 1991	U
Daphnia pulex (Water flea)	Juvenile	72h-LC50	18.86-28.31[d]	NR	S, N	Penncapthrin encapsulated formulation	14	NR	NR	7.8	Sibley & Kaushik 1991	U
Daphnia pulex (Water flea)	juvenile	48h-LC50	2.75-13.1[d]	NR	S, N	emulsifiable concentrate	14	NR	NR	7.8	Sibley & Kaushik 1991	U
Daphnia pulex (Water flea)	24h old	32d-LOEC (time to first brood)	15[d]	NR	S, N	Penncapthrin encapsulated formulation	NR	NR	NR	NR	Sibley & Kaushik 1991	U
Daphnia pulex (Water flea)	24h old	32d-LOEC (total # young produced)	1.0[d]	NR	S, N	Penncapthrin encapsulated formulation	NR	NR	NR	NR	Sibley & Kaushik 1991	U
Diaptomus spp. (Calanoid copepod)	various	48h-LC50	7.0[d]	42	S, N	Spartan® formulation	20-22	6.6-7.5	26-28	8.0-8.5	Naqvi & Hawkins 1989	U
Enellagma and Ishnura spp. (Damselfly)	nymph	24h-LC50	2.9	96	S, N	acetone	20	NR	NR	NR	Siegfried 1993	2
Eucyclops spp. (Calanoid copepod)	various	48h-LC50	5.0[d]	42	S, N	Spartan® formulation	20-22	6.6-7.5	26-28	8.0-8.5	Naqvi & Hawkins 1989	U
Gammarus pseudolimnaeus (Amphipod)	immature	96h-LC50	0.17	91	S, NR	NR	17	NR	42	7.4	Mayer & Ellersieck 1986	U
Gammarus pseudolimnaeus (Amphipod)	NR	9d-LC50	0.25 – 0.37[e]	NR	S, M	Ambush® formulation	NR	NR	NR	NR	Helson et al. 1986	U
Gammarus pulex (Amphipod)	Adult	6d-LC50	0.17	>99	R, M	no	15	7.75	NR	7.3	McLoughlin et al. 2000	2
Gammarus pulex (Amphipod)	Adult	6d-LOEC (feeding rate)	0.06 (0.009 for EC10)	>99	R, M	no	15	7.75	NR	7.3	McLoughlin et al. 2000	2
Gammarus pulex (Amphipod)	Adult	48h-LOEC (glutathione-S-transferase activity)	0.12 (0.019 for EC10)	>99	R, M	no	15	7.62	NR	7.43	McLoughlin et al. 2000	U
Gammarus pulex (Amphipod)	NR	24h[f]-LC90-95	1.0[e]	NR	F, N	NR	17.5	NR	NR	NR	Muirhead-Thomson 1978	U
Helisoma trivolvis (Snail)	NR	28d-NOEC (survival)	>0.33	92	F, M	none	15	9.2-10	34-38	7.4-7.9	Spehar et al. 1983	1

Hexagenia rigida (Burrowing mayfly)	Nymph	6h-LC50	0.58-2.06	NR	S, M	NR	22	NR	NR	NR	Friesen et al. 1983	U
Hydrophilus spp. (Diving beetle)	NR	24h-LC50	45	96	S, N	acetone	20	NR	NR	NR	Siegfried 1993	2
Hydropsyche + Cheumatopsyche spp. (Caddisfly)	larvae	24h-LC50	5.9	96	S, N	acetone	20	NR	NR	NR	Siegfried 1993	2
Hydropsyche pellucidula (Caddisfly)	larvae	24h[f]-LC90-95	100[e]	NR	F, N	NR	17.5	NR	NR	NR	Muirhead-Thomson 1978	U
Hydropsyche sp. (Caddisfly)	larvae	96h[f]-LC50	3560-5610[d]	NR	F, N	Penncapthrin encapsulated formulation	14	NR	NR	7.8	Sibley & Kaushik 1991	U
Isonychia bicolor (Mayfly)	nymph	96h[f]-LC50	12810-14010[d]	NR	F, N	Penncapthrin encapsulated formulation	14	NR	NR	7.8	Sibley & Kaushik 1991	U
Lymnaea acuminate (Snail)	adult	96-h LC50	0.37	NR	S, N	none	NR	NR	NR	NR	Singh and Agarwal 1986	U
Ophiogomphus (Dragonfly)	nymph	48h-LC50	7.4[d]	500 g/L	F, NR	Ambush® formulation	16 (days); 8 (night)	9-10	60	6.5-7.5	Poirier and Surgeoner 1987	U
Orconectes immunis (Crayfish)	adult	96h-LC50	<1.2	93	F, M	dimethylformamide	16.7	8.39	NR	8.07	Thurston et al. 1985	1
Procambarus clarkia (Crayfish)	newly hatched	96h-LC50	0.39[e]	380 g/L	S, M	Pounce® formulation	24	NR	100	8.40	Jolly et al. 1978	U
Procambarus clarkia (Crayfish)	juvenile	96h-LC50	0.438[e]	25.6	S, N	commercial formulation	21.8	NR	99.4	8.50	Jarboe & Romaire 1991	U
Procambarus clarkia (Crayfish)	juvenile	96h-LC50	0.62[e]	380 g/L	S, M	Pounce® formulation	24	NR	100	8.40	Jolly et al. 1978	U
Pteronarcys dorsata (Stonefly)[g]	nymph	21d-LOEC (EC_{100} immobility)	0.042	TG	F, M	none	15	95% saturation	46-48	7.6-7.8	Anderson 1982	1
Pycnopsyche (Caddisfly)	larvae	48h-LC50	3.2[d]	500 g/L	F, NR	Ambush® formulation	16 (days); 8 (night)	9-10	60	6.5-7.5	Poirier and Surgeoner 1987	U
Rhyacophila dorsalis (Caddisfly)	larvae	24h[g]-LC67	5.0[d]	25	F, N	Emulsifiable concentrate formulation	17	NR	NR	NR	Muirhead-Thomson 1979	U
Simulium equinum (Black fly)	larvae	24h[f]-LC90-95	5.0[e]	NR	F, N	NR	17.5	NR	NR	NR	Muirhead-Thomson 1978	U
Simulium venustum (Black fly)	larvae	48h-LC50	4.5[d]	500 g/L	F, NR	Ambush® formulation	16 (days); 8 (night)	9-10	60	6.5-7.5	Poirier and Surgeoner 1987	U

Simulium vittatum (Striped black fly)	larvae	96h[f]-LC50	1410-3580[d]	NR	F, N	Penncapthrin encapsulated formulation	14	NR	NR	7.8	Sibley & Kaushik 1991	U
Spicodiaptomus chelospinus (Calanoid copepod)	Adult	48h-LC50	5	NR	S, N	NR	29-31	NR	NR	7.4-7.75	Kader et al. 1976	U
Tanytarsus dissimilis (Midge)	Larvae	48h-LC50	<2.5	93	F, M	dimethylformamide	21.4	7.56	NR	8.07	Thurston et al. 1985	1
Thamnocephalus platyurus (Beaver-tail fairy shrimp)	larvae	24h-LC50	940	NR	S, N	acetone	25	NR	NR	7.4	Sánchez-Fortún & Barahona 2005	2
Tropocyclops prasinus (Cyclopoid copepod)	nauplius	120h LOEC (reduced density)	0.75[e]	NR	Field, N	Emulsifiable concentrate	23-30	0.03 - 8	NR	NR	Yasuno et al. 1988	U
Various mosquito species	Larvae	24h-LC50	0.12 – 3.0	NR	S, N	*cis*-permethrin in acetone	24	NR	NR	NR	Mulla et al. 1980	U
Various mosquito species	Pupae	24h-LC50	0.35 – 5.0	NR	S, N	*cis*-permethrin in acetone	24	NR	NR	NR	Mulla et al. 1980	U
Various mosquito species	Larvae	24h-LC50	0.5 – 3.0[d]	NR	S, N	Ambush ® formulation	24	NR	NR	NR	Mulla et al. 1980	U
Various mosquito species	Pupae	24h-LC50	0.7 – 6.0[d]	NR	S, N	Ambush ® formulation	24	NR	NR	NR	Mulla et al. 1980	U
Fish												
Carassius auratus (Goldfish)	juvenile	96h-LC50	>197	93	F, M	dimethylformamide	17.6	8.37	NR	7.99	Thurston et al. 1985	1
Carassius auratus (Goldfish)	juvenile	96h-LC50	>228	93	F, M	dimethylformamide	17.3	8.15	NR	8.11	Thurston et al. 1985	1
Catostomus commersonii (White sucker)	20-day larvae	96h[h]-LC50	1.0	94.4	R, M	ethanol	20.5	9	384	8.09	Holdway & Dixon 1988	1
Cyprinodon macularius (Desert pupfish)	Adult? (5-6 cm)	48h-LC50	5.0[d]	NR	S, N	Emulsifiable concentrate	11-16.6	NR	NR	NR	Mulla et al. 1978	U
Cyprinus carpio (Common carp)	15 g	48h-LC50	132	TG	S,N	acetone	28-30	NR	NR	NR	Reddy et al. 1995	U
Gambusia affinis (Western mosquitofish)	juvenile	96h-LC50	4.62	93	F, M	dimethylformamide	17.9	8.28	NR	8.28	Thurston et al. 1985	1
Gambusia affinis (Western mosquitofish)	juvenile	96h-LC50	8.02	93	F, M	dimethylformamide	19.1	7.88	NR	8.02	Thurston et al. 1985	1
Gambusia affinis (Western mosquitofish)	juvenile	96h-LC50	15[e]	380 g/L	S, M	Pounce® formulation	24	NR	100	8.40	Jolly et al. 1978	U
Gambusia affinis (Western mosquitofish)	Adult? (4-5 cm)	48h-LC50	97[d]	NR	S, N	Emulsifiable concentrate	8.8-16	NR	NR	NR	Mulla et al. 1978	U
Gambusia affinis (Western mosquitofish)	NR	24h-NOEC (mortality)	>42[e]	2	S, N	Emulsifiable concentrate	26	NR	NR	NR	Mohsen et al. 1989	U
Gambusia affinis (Western mosquitofish)	0.29 g	96h-LC50	12.0[d]	47	S, N	Spartan® formulation	20	6.5-7.0	12	7.8	Naqvi & Hawkins 1988	U

Gambusia holbrooki (Mosquitofish)	2-5 days old	48h-LC50	4.29[d]	31.28	S, N	Permanone® formulation with acetone	27	NR	NR	NR	Tietze et al. 1995	U
Gila elegans (Bonytail chub)	0.41 g	96h-LC50	>25	95.2	S, N	acetone or Triethylene glycol	22	NR	160-180	>8	Sappington et al. 2001	2
Ictalurus punctatus (Channel catfish)	juvenile	96h-LC50	2.06	93	F, M	dimethylformamide	19.1	7.88	NR	8.03	Thurston et al. 1985	1
Ictalurus punctatus (Channel catfish)	juvenile	96h-LC50	3.44	93	F, M	dimethylformamide	17.8	8.72	NR	8.02	Thurston et al. 1985	1
Ictalurus punctatus (Channel catfish)	Fry	96h-LC50	1.1[e]	380 g/L	S, M	Pounce® formulation	24	NR	100	8.40	Jolly et al. 1978	U
Ictalurus punctatus (Channel catfish)	0.7 g	96h-LC50	7.2	91	S, NR	NR	22	NR	40	7.1	Mayer & Ellersieck 1986	U
Jordanella floridae (Flagfish)	juvenile	96h[h]-LC50	540	94.4	R, M	ethanol	25.3	8.3	372	7.96	Holdway & Dixon 1988	1
Lepomis macrochirus (Bluegill sunfish)	juvenile	96h-LC50	4.56	93	F, M	dimethylformamide	18.5	8.89	NR	8.89	Thurston et al. 1985	1
Lepomis macrochirus (Bluegill sunfish)	juvenile	96h-LC50	5.81	93	F, M	dimethylformamide	18.5	9.21	NR	7.9	Thurston et al. 1985	1
Lepomis macrochirus (Bluegill sunfish)	0.7 g	96h-LC50	5.0	91	S, NR	NR	22	NR	38	7.3	Mayer & Ellersieck 1986	U
Lepomis macrochirus (Bluegill sunfish)	0.7 g	96h-LC50	6.8[c]	38.5	S, NR	Emulsifiable concentrate	22	NR	38	7.3	Mayer & Ellersieck 1986	U
Lepomis macrochirus (Bluegill sunfish)	0.5 g	96h-LC50	4.5	91	S, NR	NR	12	NR	39	7.4	Mayer & Ellersieck 1986	U
Lepomis macrochirus (Bluegill sunfish)	0.5 g	96h-LC50	8.0	91	S, NR	NR	17	NR	39	7.4	Mayer & Ellersieck 1986	U
Lepomis macrochirus (Bluegill sunfish)	0.5 g	96h-LC50	7.1	91	S, NR	NR	22	NR	39	7.4	Mayer & Ellersieck 1986	U
Lepomis macrochirus (Bluegill sunfish)	0.7 g	96h-LC50	5.6	91	S, NR	NR	22	NR	44	6.5	Mayer & Ellersieck 1986	U
Lepomis macrochirus (Bluegill sunfish)	0.7 g	96h-LC50	7.6	91	S, NR	NR	22	NR	44	7.5	Mayer & Ellersieck 1986	U
Lepomis macrochirus (Bluegill sunfish)	0.7 g	96h-LC50	7.2	91	S, NR	NR	22	NR	44	8.5	Mayer & Ellersieck 1986	U
Lepomis macrochirus (Bluegill sunfish)	0.7 g	96h-LC50	13.0	91	S, NR	NR	22	NR	44	8.0	Mayer & Ellersieck 1986	U
Lepomis macrochirus (Bluegill sunfish)	0.7 g	96h-LC50	6.2	91	S, NR	NR	22	NR	320	8.0	Mayer & Ellersieck 1986	U
Micropterus salmoides (Largemouth bass)	fingerling	96h-LC50	8.5[e]	380 g/L	S, M	Pounce® formulation	24	NR	100	8.40	Jolly et al. 1978	U
Oncorhynchus clarkii henshawi (Lahontan cutthroat trout)	0.46 g	96h-LC50	1.6	95.2	S, N	acetone or Triethylene glycol	12	NR	160-180	>8	Sappington et al. 2001	2

Oncorhynchus gilae apache (Apache trout)	0.62 g	96h-LC50	1.7	95.2	S, N	acetone or Triethylene glycol	12	NR	160-180	>8	Sappington et al. 2001	2
Oncorhynchus mykiss (Rainbow trout)	juvenile	96h-LC50	0.62	86.6	F, M	ethyl alcohol	5	NR	358-363 (EDTA)	7.9-8.2	Kumaraguru and Beamish 1981	2
Oncorhynchus mykiss (Rainbow trout)	juvenile	21d-LOEC (Growth)	0.65	NR	F, N	NR	7	8	NR	NR	Kumaraguru and Beamish 1986	2
Oncorhynchus mykiss (Rainbow trout)	juvenile	96h-LC50	0.69	86.6	F, M	ethyl alcohol	10	NR	358-363 (EDTA)	7.9-8.2	Kumaraguru and Beamish 1981	2
Oncorhynchus mykiss (Rainbow trout)	juvenile	96h-LC50	3.17	86.6	F, M	ethyl alcohol	15	NR	358-363 (EDTA)	7.9-8.2	Kumaraguru and Beamish 1981	2
Oncorhynchus mykiss (Rainbow trout)	juvenile	96h-LC50	5.47	93	F, M	dimethylformamide	9.5	9.08	NR	8	Thurston et al. 1985	1
Oncorhynchus mykiss (Rainbow trout)	0.71 g	96h-LC50	3.3	95.2	S, N	acetone or Triethylene glycol	12	NR	160-180	>8	Sappington et al. 2001	2
Oncorhynchus mykiss (Rainbow trout)	juvenile	96h-LC50	6.43	86.6	F, M	ethyl alcohol	20	NR	358-363 (EDTA)	7.9-8.2	Kumaraguru and Beamish 1981	2
Oncorhynchus mykiss (Rainbow trout)	juvenile	96h-LC50	7	91.9	F, M	No	15.6	9.3	45.3	7-7.4	Holcombe et al. 1982	2
Oncorhynchus mykiss (Rainbow trout)	fingerling	24h-LC50	61[c]	92-96	S, M	Commercial formulation	10	NR	100	7.50	Coats and O'Donnell-Jeffery 1979	U
Oncorhynchus mykiss (Rainbow trout)	fingerling	24h-LC50	135	92-96	S, M	Acetone	10	NR	100	7.50	Coats and O'Donnell-Jeffery 1979	2
Oncorhynchus mykiss (Rainbow trout)	adult	96h-LC50	314	NR	F, M	ethyl alcohol	15	NR	358-363 (EDTA)	7.9-8.2	Kumaraguru and Beamish 1986	2
Oncorhynchus mykiss (Rainbow trout)	Juvenile? (5-6 cm)	48h-LC50	6.0[d]	NR	S. N	Emulsifiable concentrate formulation	12-25.5	NR	NR	NR	Mulla et al. 1978	U
Oncorhynchus mykiss (Rainbow trout)	0.7 g	96h-LC50	4.1	91	S, NR	NR	12	NR	44	7.2	Mayer & Ellersieck 1986	U
Oncorhynchus mykiss (Rainbow trout)	0.6 g	24h-LC50	4.3[c]	38.5	S, NR	Emulsifiable concentrate	12	NR	40	7.1	Mayer & Ellersieck 1986	U
Oncorhynchus mykiss (Rainbow trout)	0.8 g	96h-LC50	2.9	91	S, NR	NR	7	NR	40	7.0	Mayer & Ellersieck 1986	U
Oncorhynchus mykiss (Rainbow trout)	0.8 g	96h-LC50	4.1	91	S, NR	NR	12	NR	40	7.0	Mayer & Ellersieck 1986	U
Oncorhynchus mykiss (Rainbow trout)	0.8 g	96h-LC50	6.0	91	S, NR	NR	17	NR	40	7.0	Mayer & Ellersieck 1986	U
Oncorhynchus mykiss (Rainbow trout)	1.1 g	96h-LC50	6.3	91	S, NR	NR	12	NR	40	6.5	Mayer & Ellersieck 1986	U

Oncorhynchus mykiss (Rainbow trout)	1.1 g	96h-LC50	7.0	91	S, NR	NR	12	NR	40	7.5	Mayer & Ellersieck 1986	U
Oncorhynchus mykiss (Rainbow trout)	1.1 g	96h-LC50	8.2	91	S, NR	NR	12	NR	40	8.5	Mayer & Ellersieck 1986	U
Oncorhynchus mykiss (Rainbow trout)	0.7 g	96h-LC50	4.2	91	S, NR	NR	12	NR	40	8.1	Mayer & Ellersieck 1986	U
Oncorhynchus mykiss (Rainbow trout)	0.7 g	96h-LC50	5.2	91	S, NR	NR	12	NR	320	8.1	Mayer & Ellersieck 1986	U
Oncorhynchus mykiss (Rainbow trout)	NR	24h-LC50	18	93	S, N	NR	12	NR	NR	NR	Glickman et al. 1982	U
Oncorhynchus mykiss (Rainbow trout)	NR	24h-LC50	25	99	S, N	NR (cis-permethrin)	12	NR	NR	NR	Glickman et al. 1982	U
Oncorhynchus mykiss (Rainbow trout)	NR	24h-LC50	14	99	S, N	NR (trans-permethrin)	12	NR	NR	NR	Glickman et al. 1982	U
Oryzias latipes (Japanese medaka)	juvenile	48h-LC50	11	88	R, N	acetone	25	7.1	136	7.30	Rice et al. 1997	1
Oryzias latipes (Japanese medaka)	adult	48h-LC50	38	99	R, N	ethanol (cis-permethrin)	22	NR	NR	NR	Kikuchi et al. 1984	2
Oryzias latipes (Japanese medaka)	adult	48h-LC50	55	99	R, N	ethanol (trans-permethrin)	22	NR	NR	NR	Kikuchi et al. 1984	2
Oryzias latipes (Japanese medaka)	adult	48h-LC50	60[d]	NR	R, N	Ambush® formulation	22	NR	NR	NR	Kikuchi et al. 1984	U
Oryzias latipes (Japanese medaka)	NR	48h-LC50	13 – 41[e]	NR	NR	NR	NR	NR	NR	NR	Miyamoto 1976	U
Pimephales promelas (Fathead minnow)	Larvae	32d-NOEC (Survival)	0.66	92	F, M	No	25	5.3-7.8	34-38	7.4-7.9	Spehar et al. 1983	1
Pimephales promelas (Fathead minnow)	Larvae	32d-LOEC (Survival)	1.4	92	F, M	No	25	5.3-7.8	34-38	7.4-7.9	Spehar et al. 1983	1
Pimephales promelas (Fathead minnow)	juvenile	96h-LC50	6.4	93	F, M	dimethylformamide	17.7	8.94	NR	7.99	Thurston et al. 1985	1
Pimephales promelas (Fathead minnow)	0.41 g	96h-LC50	9.4	95.2	S, N	acetone or Triethylene glycol	22	NR	160-180	>8	Sappington et al.2001	2
Pimephales promelas (Fathead minnow)	juvenile	96h-LC50	15.6	91.9	F, M	No	25.1	7.3	45.3	7-7.4	Holcombe et al. 1982	2
Pimephales promelas (Fathead minnow)	0.6 g	96h-LC50	5.7	91	S, NR	NR	22		38	7.3	Mayer & Ellersieck 1986	U
Pimephales promelas (Fathead minnow)	0.6 g	96h-LC50	5.7[c]	38.5	S, NR		22		38	7.3	Mayer & Ellersieck 1986	U
Poecilia reticulata (Guppy)	adult	48h-LC50	245.7	94.9	S, N	acetone	20	7.8-8	NR	NR	Başer et al. 2003	2
Ptychocheilus lucius (Colorado pikeminnow)	0.33 g	96h-LC50	24	95.2	S, N	acetone or Triethylene glycol	22	NR	160-180	>8	Sappington et al.2001	2

Salvelinus fontinalis (Brook trout)	Juvenile (42 mm)	96h-LC50	2.86	>92	S, N	acetone	9.5	>8.0	132	8.1	Paul et al. 2005	2
Salvelinus fontinalis (Brook trout)	Juvenile (37 mm)	6h- LOEC (swimming)	3.2	>92	S, N	acetone	9.5	>8.0	132	8.1	Paul et al. 2005	2
Salvelinus fontinalis (Brook trout)	1.2 g	96h-LC50	3.2	92.5	S, NR	NR	12	NR	40	7.5	Mayer & Ellersieck 1986	U
Salvelinus fontinalis (Brook trout)	1.2 g	96h-LC50	5.2[c]	57	S, NR	Emulsifiable concentrate	12	NR	40	7.5	Mayer & Ellersieck 1986	U
Salvelinus fontinalis (Brook trout)	1.2 g	96h-LC50	2.3[c]	13.3	S, NR	Emulsifiable concentrate	12	NR	40	7.5	Mayer & Ellersieck 1986	U
Tilapia mossambica (Mozambique tilapia)	Adult? (4-5 cm)	48h-LC50	44[d]	NR	S, N	Emulsifiable concentrate formulation	15-21.4	NR	NR	NR	Mulla et al. 1978	U
Xyrauchen texanus (Razorback sucker)	0.32 g	96h-LC50	6.0	95.2	S, N	acetone or Triethylene glycol	22	NR	160-180	>8	Sappington et al. 2001	2
Amphibians												
Bufo americanus (American toad)	tadpole	22h-LOEC (mortality)	50	NR	S, N	Acetone or acetone:ethanol	15	NR	NR	NR	Berrill et al. 1993	U
Rana catesbeiana (Bullfrog)	tadpole	96h-LC50	115	93	F, M	dimethylformamide	17.9	8.37	NR	8	Thurston et al. 1985	1
Rana catesbeiana (Bullfrog)	tadpole	96h-LC50	7033[e]	380 g/L	S, M	Pounce® formulation	24	NR	100	8.40	Jolly et al. 1978	U
Rana clamitans (Green frog)	Embryo to tadpole	96h-LOEC (deformed tail, behaviour)	100	NR	R, N	Acetone or acetone:ethanol	15	NR	NR	NR	Berrill et al. 1993	U
Rana clamitans (Green frog)	tadpole	96h-LOEC (growth, measured 13d after exposure)	100	NR	R, N	Acetone or acetone:ethanol	15	NR	NR	NR	Berrill et al. 1993	U
Rana pipiens (Northern leopard frog)	tadpole	22h-LOEC (mortality)	50	NR	S, N	Acetone or acetone:ethanol	15	NR	NR	NR	Berrill et al. 1993	U
Rana sphenocephala (Southern leopard frog)	tadpole	96h-LC50	18.2	NR	S, M	acetone	22	NR	NR	NR	Bridges et al. 2002	2
Protozoa												
Tetrahymena pyriformis (ciliate)	NA	5d-LOEC (cell number)	10000	NR	S, N	acetone	27	NR	NR	7.0	Kumar et al. 1989	U

NA – Not Applicable; NR - Not Reported; TG – Technical Grade

[a] F - Flowthrough; S - Static; R – Renewal; M – Measured; N – Nominal

[b] 1 – Primary; 2 – Secondary; U – Unacceptable

[c] Although this concentration is expressed in terms of the active ingredient, a formulated product was used. Because of the presence of substances in the formulation that may have affected toxicity, this data is not acceptable for use in deriving the guideline.

[d] These concentrations are expressed in terms of the formulated product, not as concentrations of the active ingredient. In Poirier & Surgeoner (1987), the formulated product, Ambush®, contained permethrin at a concentration of 500 g/L.

[e] It is not clear in the study whether these concentrations are expressed in terms of the active ingredient, or the formulated product. In Jolly et al. (1978), the formulated product was Pounce® which contained 0.38 kg/L of permethrin. In Jarboe & Romaire (1991), the formulation was an emulsifiable concentrate containing 25.6% active ingredient. In Mokry & Hoagland (1990) the formulated product was Ambush® with 25.6% active ingredient (w/v).

[f] Exposure to permethrin was only for one hour, then organisms were transferred to clean water and effects were observed later.

[g] Exposure to permethrin was only for 15 minutes, then organisms were transferred to clean water and effects were observed later.

[h] This test used a 2-hour pulse exposure, with effects observed later after 96 hours.

[g] Critical study used to derive freshwater guidelines.

Appendix B. SUMMARY OF MARINE TOXICITY STUDIES FOR PERMETHRIN

Organism	Life Stage	Endpoint	Effect conc. (µg a.i./L)	% a.i.	Test Type[a]	Carrier or formulant	Temp (°C)	DO (mg/L)	Salinity (‰)	pH	Reference	Rank[b]
Algae / Plants												
Skeletonema costatum (Diatom)	NA	96h-EC50 (cell count)	68	TG	S, N	acetone	20	NR	NR	8.1	Walsh & Alexander 1980	2
Skeletonema costatum (Diatom)	NA	96h-EC50 (biomass)	72	TG	S, N	acetone	20	NR	NR	8.1	Walsh & Alexander 1980	2
Skeletonema costatum (Diatom)	NA	96h-EC50 (growth)	92, 124	93	S, N	acetone	20	NR	30	8.1	Borthwick & Walsh 1981	2
Invertebrates												
Artemia franciscana (San Francisco brine shrimp)	larvae	24h-LC50	8210	NR	S, N	acetone	25	NR	35	8.6	Sánchez-Fortún & Barahona 2005	2
Brachionus plicatilis (Rotifer)	larvae	24h-LC50	900	NR	S, N	acetone	25	NR	35	8.6	Sánchez-Fortún & Barahona 2005	2
Crangon septemspinosa (Sand shrimp)	1.3 g	96h-LC50	0.13	92.1	R, M	ethanol	12	NR	NR	NR	McLeese et al. 1980	2
Crassostrea virginica (Easter oyster)	Embryo	48h-EC50 (abnormal development)	>1000	93	S, N	NR	25	NR	20	NR	Borthwick & Walsh 1981	U
Homarus americanus (Lobster)	Adult (450 g)	96h-LC50	0.73	92.1	R, M	ethanol	11	NR	NR	NR	McLeese et al. 1980	2
Homarus americanus (Lobster)	Adult	650h-LT50	0.76	NR	R, M	ethanol	10	NR	30	NR	Zitko et al. 1979	U
Homarus americanus (Lobster)	Adult	96h-LC50	7	NR	R, M	ethanol	10	NR	30	NR	Zitko et al. 1979	U
Menippe mercenaria (Stone crab)	Larvae	96h-LC50	0.018	93	S, N	NR	25	NR	20	NR	Borthwick & Walsh 1981	2
Mysidopsis bahia (Mysid)	Juvenile	96h-LC50	0.046	93	S, N	NR	25	NR	20	NR	Borthwick & Walsh 1981	2
Mysidopsis bahia (Mysid)[f]	Newly hatched, < 24h	96h-LC50	0.02	93	F, N	Triethylene glycol	26	NR	25	NR	Schimmel et al. 1983	1

Mysidopsis bahia (Mysid)	Juvenile	96h-LC50	0.095	99.9?	S, N	Triethylene glycol & acetone	25	5.9	25	7.8-8.1	Cripe 1994	2
Mytilus edulis (Blue mussel)	25-40 mm	7d-EC67 (feeding rate)	400	97	R, N	acetone	15	NR	33-35	NR	Donkin et al. 1997	U
Nitocra spinipes (Harpacticoid)	Adult	96h-LC50	0.6[c]	250 g/L	S, N	acetone	21	>5	7	7.8	Lindén et al. 1979	U
Paleomonetes pugio (Grass shrimp)	< 24h old	48h-LC50	0.049[e]	31.28	S, N	Permanone® formulation with acetone	27	NR	15	NR	Tietze et al. 1995	U
Penaeus duorarum (Pink shrimp)	NR	96h-LC50	0.22	93	F, M	Triethylene glycol	24.9	NR	25	NR	Schimmel et al. 1983	1
Penaeus duorarum (Pink shrimp)	Postlarvae	96h-LC50	0.17	99.9?	S, N	Triethylene glycol & acetone	25	5.6	25	7.5-7.9	Cripe 1994	2[d]
Fish												
Alburnus alburnus (Bleak)	8 cm	96h-LC50	4 – 8[c]	250 g/L	S, N	acetone	10	>5	7	7.8	Lindén et al. 1979	U
Atherinops affinis (Topsmelt)	Larvae	96h-LC50	25.3	93	S, N	Triethylene glycol	20	45-99% saturation	20	7.1-8.2	Hemmer et al. 1992	2
Cyprinodon bovinus (Leon Springs pupfish)	0.42 g	96h-LC50	21	95.2	S, N	Acetone or triethylene glycol	20	NR	2	NR	Sappington et al. 2001	2
Cyprinodon variegatus (Sheepshead minnow)	NR	96h-LC50	7.8	93	F, M	Triethylene glycol	30	NR	25	NR	Schimmel et al. 1983	1
Cyprinodon variegatus (Sheepshead minnow)	Embryo-Larva	28d-NOEC (Survival)	10	93	F, M	Triethylene glycol	30	3.8-6.6	22-32	NR	Hansen et al. 1983	2
Cyprinodon variegatus (Sheepshead minnow)	Embryo-Larva	28d-LOEC (Survival)	22	93	F, M	Triethylene glycol	30	3.8-6.6	22-32	NR	Hansen et al. 1983	2
Cyprinodon variegatus (Sheepshead minnow)	Fry	96h-LC50	88	93	S, N	NR	25	NR	20	NR	Borthwick & Walsh 1981	2
Cyprinodon variegatus (Sheepshead minnow)	0.24 g	96h-LC50	17	95.2	S, N	Acetone or triethylene glycol	20	NR	2	NR	Sappington et al. 2001	2
Cyprinodon variegatus (Sheepshead minnow)	8-11 days old	48h-LC50	3.02[e]	31.28	S, N	Permanone® formulation with acetone	27	NR	8	NR	Tietze et al. 1995	U
Menidia beryllina (Inland silverside)	Larvae	96h-LC50	27.5	93	S, N	Triethylene glycol	25	45-99% saturation	20	7.1-8.2	Hemmer et al. 1992	2

Menidia beryllina (Inland silverside)	13-17 days old	48h-LC50	2.86[e]	31.28	S, N	Permanone® formulation with acetone	27	NR	8	NR	Tietze et al. 1995	U
Menidia menidia (Atlantic silverside)	NR	96h-LC50	2.2	93	F, M	Triethylene glycol	25.5	NR	25	NR	Schimmel et al. 1983	1
Mugil cephalus (Striped mullet)	NR	96h-LC50	5.5	93	F, M	Triethylene glycol	24.5	NR	25	NR	Schimmel et al. 1983	1
Salmo salar (Atlantic salmon)	NR	96h-LT50	8.8	92.1	R, M	ethanol	10	NR	30	NR	Zitko et al. 1977; 1979	U
Salmo salar (Atlantic salmon)	juvenile	96h-LC50	12	92.1	R, M	ethanol	10	NR	NR	NR	McLeese et al. 1980	2

NA – Not Applicable; NR - Not Reported; TG – Technical Grade

[a] F - Flowthrough; S - Static; R – Renewal; M – Measured; N – Nominal

[b] 1 – Primary; 2 – Secondary; U – Unacceptable

[c] It is not clear in the study whether these concentrations are expressed in terms of the active ingredient, or the formulated product (Ambush® which contained 250 g/L of permethrin).

[d] Mortality in the solvent control of this study was high, at 15%. However, due to the lack of mortality in the seawater-only control, and only 5% mortality at the lowest concentration of permethrin (which contained the same solvent concentration as the solvent control), it is not likely that the high mortality resulted from adverse exposure conditions or effects of the solvent. Therefore, the study has been classified as acceptable.

[e] This concentration is expressed in terms of the formulated product, not as a concentration of the active ingredient.

[f] Critical study used to derive marine water guidelines.

Appendix C. U.S. EPA PESTICIDE EFFECTS DATABASE DATA FOR PERMETHRIN (U.S. EPA 2004)

Taxa	Common Name	Latin	Age	Type	% a.i.	Dur-ation	End-point	Toxicity (ppb)	Confidence Limits	NOEL	Study Date	Cate-gory	EPA ID	Lab Code
Fishes	Atlantic salmon	*Salmo salar*	N.R.	S	Tech	96 hr	LC50	1.5	1.1-2.0	0.75	1976	C	N.R.	EGG
Fishes	Atlantic silverside	*Menidia menidia*	Adult	F	93	96 hr	LC50	2.2	1.2-6.4	N.R.	1986	S	40228401	EPA
Fishes	Bluegill sunfish	*Lepomis macrochirus*	1.6 g	F	Tech	96 hr	LC50	0.79	N.R.	0.68	1976	S	ES-F3	BRI
Fishes	Bluegill sunfish	*Lepomis macrochirus*	N.R.	NR	24EC	96 hr	LC50	10.8	N.R.	4.7	1976	S	ESI	BRI
Fishes	Bluegill sunfish	*Lepomis macrochirus*	1.7 g	S	24EC	96 hr	LC50	13	11-16	<7	1977	C	42277001	BRI
Fishes	Bluegill sunfish	*Lepomis macrochirus*	1.0 g	S	94.4	96 hr	LC50	13.3	9-19	N.R.	1978	C	USEPALAB	ARC
Fishes	Bluegill sunfish	*Lepomis macrochirus*	1.0 g	S	91.4	96 hr	LC50	13.5	9-19	4.2	1978	C	USEPALAB	ARC
Fishes	Bluegill sunfish	*Lepomis macrochirus*	N.R.	S	95.7	96 hr	LC50	2.52	1.88-3.36	<1.0	1976	C	096699	UCE
Fishes	Bluegill sunfish	*Lepomis macrochirus*	0.7 g	F	10EC	96 hr	LC50	24	17-31	<0.6	1992	C	42584004	BRI
Fishes	Bluegill sunfish	*Lepomis macrochirus*	0.52 g	F	FORM	96 hr	LC50	32	N.R.	6.8	1977	S	0097445	ICI
Fishes	Bluegill sunfish	*Lepomis macrochirus*	N.R.	S	38.4	96 hr	LC50	33.4	26.6-41.5	20	1975	C	096699	EGG
Fishes	Bluegill sunfish	*Lepomis macrochirus*	0.7 g	S	91	96 hr	LC50	5.0	3.1-7.9	N.R.	1986	C	40098001	FWS
Fishes	Bluegill sunfish	*Lepomis macrochirus*	N.R.	S	100	96 hr	LC50	6.1	5.1-7.3	3.2	1974	C	096699	BIO
Fishes	Bluegill sunfish	*Lepomis macrochirus*	0.7g	S	38.5	96 hr	LC50	6.8	5.3-8.7	N.R.	1986	S	40098001	FWS
Fishes	Bluegill sunfish	*Lepomis macrochirus*	0.89g	S	Tech	96 hr	LC50	6.8	4.6-10.0	4.6	1979	C	0043263	BIO
Fishes	Bluegill sunfish	*Lepomis macrochirus*	0.7 g	S	38.5	96 hr	LC50	9.0	7.0-11.5	N.R.	1978	C	USEPALAB	ARC
Aves	Bobwhite quail	*Colinus virginianus*	N.R.	D	95.7	8 D	LC50	>10000000	N.A.	10000	1975	C	096699	TFI
Aves	Bobwhite quail	*Colinus virginianus*	ErlyLf	R	92.4	20WKS	LOEL	>25000	N.R.	25	1976	C	096699	WLI
Aves	Bobwhite quail	*Colinus virginianus*	ErlyLf	R	95.2	20WKS	LOEL	>500000	N.A.	500	1992	C	42322901	WLI

Aves	Bobwhite quail	*Colinus virginianus*	10 D	D	93.4	8 D	LC50	>5200000	N.R.	N.R.	1991	C	4188802	HRC
Fishes	Brook trout	*Salvelinus fontinalis*	1.2 g	S	13EC	96 hr	LC50	2.3	1.4-3.7	N.R.	1986	S	40098001	FWS
Fishes	Brook trout	*Salvelinus fontinalis*	1.2g	S	92.5	96 hr	LC50	3.2	2.2-4.8	N.R.	1986	C	40098001	FWS
Fishes	Brook trout	*Salvelinus fontinalis*	N.R.	S	Tech	96 hr	LC50	3.9	3.1-4.8	N.R.	1977	S	ES-G-2	ICI
Fishes	Brook trout	*Salvelinus fontinalis*	1.2g	S	5.7	96 hr	LC50	5.2	3.5-7.9	N.R.	1986	S	40098001	FWS
Crustacea	Brown shrimp	*Penaeus aztecus*	N.R.	S	89	96 hr	LC50	0.34	0.26-0.48	0.16	1977	C	096699	EGG
Fishes	Carp	*Cyprinus carpio*	N.R.	F	Tech	96 hr	LC50	15	N.R.	3.3	1976	S	ES-F3	BRI
Fishes	Channel catfish	*Ictalurus punctatus*	N.R.	S	Tech	96 hr	LC50	5.4	3.9-7.4	4.2	1976	C	228186	ICI
Fishes	Channel catfish	*Ictalurus punctatus*	0.7 g	S	91	96 hr	LC50	7.2	5.7-9.0	N.R.	1986	C	40098001	FWS
Fishes	Coho salmon	*Oncorhynchus kisutch*	N.R.	S	Tech	96 hr	LC50	17	13-24	7.5	1976	C	228186	EGG
Crustacea	Crayfish	*Procambarus blandingii*	N.R.	F	89.1	96 hr	LC50	210	130-330	N.R.	1977	C	096699	EGG
Mollusca	Eastern oyster	*Crassostrea virginica*	EmbLrv	S	93	48 hr	EC50	>1000	N.R.	N.R.	1986	S	40228401	EPA
Mollusca	Eastern oyster	*Crassostrea virginica*	SPAT	F	95.7	96 hr	EC50	>40.7	N.R.	<40.7	1975	S	09669	BIO
Mollusca	Eastern oyster	*Crassostrea virginica*	SPAT	F	95.7	96 hr	EC50	>536	N.R.	95.7	1975	C	096699	EGG
Fishes	Fathead minnow	*Pimephales promelas*	LifCyc	SR	95.7	246 D	LOEC	0.41	N.A.	0.30	1977	S	096699	EGG
Fishes	Fathead minnow	*Pimephales promelas*	N.R.	S	Tech	96 hr	LC50	3.0	1.0-9.0	1.5	1977	C	ES-F1	ICI
Fishes	Fathead minnow	*Pimephales promelas*	0.6 g	S	91	96 hr	LC50	5.7	4.1-7.9	N.R.	1986	C	40098001	FWS
Crustacea	Fiddler crab	*Uca pugilator*	N.R.	S	95.7	96 hr	LC50	2.39	1.82-3.25	N.R.	1975	C	096699	EGG
Crustacea	Fiddler crab	*Uca pugilator*	Adult	S	89	96 hr	LC50	2.65	1.68-4.16	0.85	1977	S	ES-L,N	BIO
Crustacea	Fiddler crab	*Uca pugilator*	N.R.	S	40.6	96 hr	LC50	7.6	6.03-9.56	N.R.	1975	S	096699	EGG
Fishes	Inland silverside	*Menidia beryllina*	0.035g	F	94.6	96 hr	LC50	6.1	5.1-7.5	<2.1	1989	C	41874901	HEL

Aves	Japanese quail	*Coturnix japonica*	N.R.	D	Tech	8 D	LC50	>23000000	N.R.	4600	1976	S	227722	HRC
Aves	Mallard duck	*Anas platyrhynchos*	N.R.	D	92	8 D	LC50	>23000000	N.R.	2300	1976	C	227722	HRC
Aves	Mallard duck	*Anas platyrhynchos*	ErlyLf	R	92.4	20WKS	LOEL	>25000	N.R.	25	1976	C	096699	WLI
Aves	Mallard duck	*Anas platyrhynchos*	ErlyLf	R	95.2	20WKS	LOEL	500000	N.A.	125	1992	C	42322902	WLI
Aves	Mallard duck	*Anas platyrhynchos*	7 D	D	93.4	8 D	LC50	>5200000	N.R.	>5200	1991	C	41888403	HRC
Aves	Mallard duck(Male)	*Anas platyrhynchos*	N.R.	D	95.7	8 D	LC50	>10000000	N.R.	<10000	1975	C	096699	TFI
Aquatic Plants	Marine diatom	*Skeletonema costatum*	N.R.	S	93	96 hr	EC50	92	71-120	N.R.	1986	C	40228401	EPA
Insecta	Mayfly	*Hexagenia bilineata*	Nymph	F	97	96 hr	LC50	0.1	0.085-0.12	0.021	1980	C	Rep:23648	ABC
Insecta	Midge	*Chironomus plumosus*	3rd-I	S	91	48 hr	LC50	0.56	0.18-1.65	N.R.	1986	S	40098001	FWS
Crustacea	Mysid	*Mysidopsis bahia*	Adult	F	93	96 hr	LC50	0.019	0.016-0.02	N.R.	1986	S	40228401	EPA
Crustacea	Mysid	*Mysidopsis bahia*	1 D	F	93	96 hr	LC50	0.02	0.017-0.02	N.R.	1986	S	40228401	EPA
Crustacea	Mysid	*Mysidopsis bahia*	1 D	S	93	96 hr	LC50	0.046	0.03-0.056	N.R.	1986	S	40228401	EPA
Crustacea	Mysid	*Mysidopsis bahia*	N.R.	S	90.8	96 hr	LC50	0.075	N.R.	N.R.	1986	C	43492902	BRI
Mollusca	Pacific oyster	*Crassostrea gigas*	EmbLrv	S	Tech	48 hr	EC50	>1050	N.R.	1.05	1977	S	096325	ICI
Mollusca	Pacific oyster	*Crassostrea gigas*	Emblrv	S	10EC	48 hr	EC50	6500	6100-6900	2700	1992	C	42723301	BRI
Crustacea	Pink shrimp	*Penaeus duorarum*	Adult	F	93	96 hr	LC50	0.22	0.06-0.79	N.R.	1986	C	40228401	EPA
Crustacea	Pink shrimp	*Penaeus duorarum*	N.R.	NR	95.7	96 hr	LC50	0.35	0.29-0.44	N.R.	1975	C	096699	BIO
Crustacea	Pink shrimp	*Penaeus duorarum*	N.R.	S	40.6	96 hr	LC50	0.51	0.35-0.76	N.R.	1975	C	096699	EGG
Mollusca	Pond snail	*Lymnaea stagnalis*	Adult	S	25EC	48 hr	LC50	<100000	N.R.	10	1976	S	ES-K	ICI
Fishes	Rainbow trout	*Oncorhynchus mykiss*	0.3 g	F	Tech	96 hr	LC50	2.1	N.R.	1.0	1976	S	ESG-1	NR
Fishes	Rainbow trout	*Oncorhynchus mykiss*	0.8 g	S	91	96 hr	LC50	2.9	2.0-4.2	N.R.	1986	C	40098001	FWS
Fishes	Rainbow trout	*Oncorhynchus mykiss*	N.R.	S	38.4	96 hr	LC50	20.9	15.8-27.9	8.4	1975	C	096699	EGG

Fishes	Rainbow trout	*Oncorhynchus mykiss*	0.51g	S	94	96 hr	LC50	5.3	N.R.	2.2	1979	S	0043265	EGG
Fishes	Rainbow trout	*Oncorhynchus mykiss*	N.R.	S	24EC	96 hr	LC50	5.6	4.9-6.4	4.2	1977	S	ES-J	ICI
Fishes	Rainbow trout	*Oncorhynchus mykiss*	1.8 g	F	10EC	96 hr	LC50	72	60-89	0.48	1992	C	42584003	BRI
Fishes	Rainbow trout	*Oncorhynchus mykiss*	1.52 g	F	26.2	96 hr	LC50	8.4	6.8-11.2	0.45	1995	C	43740601	BRI
Fishes	Rainbow trout	*Oncorhynchus mykiss*	N.R.	S	100	96 hr	LC50	9.8	7.7-12.6	3.2	1974	C	096699	BIO
Aves	Ring-necked pheasant	*Phasianus colchicus*	N.R.	D	92	8 D	LC50	>23000000	N.A.	N.R.	1976	C	75839	HRC
Crustacea	Scud	*Gammarus pseudolimnaeus*	Juv	S	91	96 hr	LC50	0.17	0.11-0.27	N.R.	1986	C	40098001	FWS
Fishes	Sheepshead minnow	*Cyprinodon variegatus*	ErlyLf	F	N.R.	28 D	LOEC	10	N.A.	<10	N.R.	S	N.R.	EPA
Fishes	Sheepshead minnow	*Cyprinodon variegatus*	0.6 g	F	10EC	96 hr	LC50	>300	N.A.	N.R.	1992	S	42608201	ICI
Fishes	Sheepshead minnow	*Cyprinodon variegatus*	Adult	S	93	96 hr	LC50	7.8	6.2-10	N.R.	1986	S	40228401	EPA
Fishes	Sheepshead minnow	*Cyprinodon variegatus*	28D	S	93	96 hr	LC50	88	82-95	N.R.	1986	S	40228401	EPA
Crustacea	Stone crab	*Menippe mercenaria*	Larvae	S	93	96 hr	EC50	0.018	0.01-0.03	N.R.	1986	C	40228401	EPA
Fishes	Striped mullet	*Mugil cephalus*	Juv	F	93	96 hr	LC50	5.5	4.1-7.4	N.R.	1986	C	40098001	EPA
Crustacea	Water flea	*Daphnia magna*	12 hr	S	95.7	96 hr	EC50	0.039	0.025-0.06	0.032	1975	C	228186	BIO
Crustacea	Water flea	*Daphnia magna*	LifCyc	F	98.6	21 D	LOEC	0.084	N.A.	0.039	1995	C	43745701	BRI
Crustacea	Water flea	*Daphnia magna*	N.R.	S	38.4	48 hr	EC50	0.112	0.076-.164	0.084	1975	C	096699	EGG
Crustacea	Water flea	*Daphnia magna*	ErlyLf	F	94.8	21 d	LOEC	0.118	N.R.	0.06	1980	IN	00047033	ABC
Crustacea	Water flea	*Daphnia magna*	N.R.	S	Tech	48 hr	EC50	0.32	0.24-0.44	0.1	1976	C	096699	BIO
Crustacea	Water flea	*Daphnia magna*	LifCyc	NR	94.4	28 D	LOEC	0.56	N.A.	0.28	1978	S	USEPALAB	ARC
Crustacea	Water flea	*Daphnia magna*	12 hr	S	98.7	48 hr	EC50	0.6	0.5-0.67	N.R.	1977	C	ES-K	ICI
Crustacea	Water flea	*Daphnia magna*	12 hr	S	25EC	48 hr	EC50	0.76	0.66-0.88	N.R.	1977	S	ES-K	ICI

Crustacea	Water flea	*Daphnia magna*	<24 hr	S	26.2	48 hr	EC50	0.86	0.72-1.02	0.33	1995	C	43740602	BRI
Crustacea	Water flea	*Daphnia magna*	1st-I	S	91	48 hr	EC50	1.26	0.63-2.49	N.R.	1986	S	40098001	FWS
Crustacea	Water flea	*Daphnia magna*	1st-I	S	25EC	48 hr	EC50	1.3	1.2-1.5	N.R.	1977	C	ES-K	ICI
Crustacea	Water flea	*Daphnia magna*	<24 hr	S	24EC	48 hr	EC50	1.5	1.0-2.1	0.5	1977	S	42277004	BRI
Crustacea	Water flea	*Daphnia magna*	<24 hr	S	95.7	48 hr	EC50	7.2	5.8-8.9	<1.8	1976	C	096699	BIO
Crustacea	Water flea	*Daphnia magna*	<24 hr	S	10EC	48 hr	EC50	9.9	8.0-12	2.3	1992	C	42584002	BRI

Note: For an explanation of codes used in this table, please refer to U.S. EPA 2004.